WTT EXPO '92

WEAPONS TRAINING TEAM

Proceedings for the

NAVAIR Third Annual Airborne Weapons Training Exposition and Technology Review

San Diego, California
January 14-16
1992

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FOREWORD

The third annual Airborne Weapons Technology Review and Training Exposition was held 14-16 January 1992 at the Princess Resort Hotel in San Diego, CA. The theme of the Exposition was weapons training for the year 2000 and the objective was to exchange training technologies of "today and tomorrow." The Expo was sponsored by Naval Air Systems Command (NAVAIRSYSCOM), PMA 205 and hosted by RDT&E Division of The Naval Command Control and Ocean Surveillance Center (NCCOSC).

The mission of the Weapons Training 2000 Program is to design, develop, and execute efficient, cost-effective weapons training programs in support of Fleet operational readiness and maintenance objectives worldwide. To accomplish this mission NAVAIRSYSCOM organized a Weapons Training Team (WTT), headed by Mr. William Walker, PMA 205-1H. The team includes several Training Systems Managers (TSM) within PMA 205 and the field activities. This team has developed a Strategic Plan which describes the approach to effectively enhance Naval training in the face of escalating demands and diminishing resources.

The Weapons Training Team was organized in 1987 and every year the team gains more support. They have become more cohesive in 1992 utilizing lessons learned to identify requirements for training, staffing and Life Cycle Cost (LCC). A sample of their goals are: interactive multimedia, computer-driven integrated training systems, deployable/distributive training, telecommunications, and possibly most important training standardization.

During the course of the Expo there were a number of speakers from government, industry and academia, that presented the very latest in Weapons Training Technology. Everything from a training system specification (in-process) to a visual/voice activated, hands-free computer (in phase I) was discussed. Several Computer Based Training (CBT) programs were explained indepth, stating that in their development, existing hardware and software were utilized and integrated with existing Personal Computers (PCs).

Training on actual equipment is almost a thing of the past and trainers (simulators) are becoming very expensive. Therefore, the less expensive CBT technology appears to provide a "better way" to train. Naval and civilian personnel can be trained more quickly, efficiently, and to a higher level of proficiency with CBT and other new technologies.

The opening remarks of Captain Walther of NCCOSC, the Introduction by Mr. Walker, and the keynote address by captain Johannsen, PMA 205, all dealt with the latest reorganizations and reduction in force and funding. All DoD agencies must prepare to do more training themselves with less funding. Business practices need to change also; selecting a "best value" contract over the lowest bid contract can mean a savings in the long run.

The new technology, whether in the development stage or an actual program in use, is truly amazing. Such advances as the touch screen, 3-D visual and audio, micro, and hands-free computers have endless applications. In some cases this new technology represents teaming with competitors. The technology is present today to make a viable paperless technical manual. The future may bring technology that has built-in (or embedded) training, much like Built-in Test (BIT) of today. Training must be the number one priority and Total Quality Management/Total Quality Leadership (TQM/TQL) was stressed to all participants.

The Expo offered additional programming such as exhibits on display for those who wished to have some hands-on experience. Many of the CBT devices which were discussed could be seen and operated at the exhibits. Tours were also offered to those who wanted to visit NAS Miramar or NAS North Island to see training facilities and associated trainers and simulators. Guest speakers during the lunch breaks and banquet were informative. Panel discussions brought out some suggestions that will be staffed and considered for the next annual Expo. It was observed that few Navy users were in attendance, however, this team/program is still very new and additional meetings like this will attract more Fleet endline users.

Master of Ceremony duties were performed by Mr. Joshua Johnson of NCCOSC who opened the meeting and kept the program moving along to keep the audience's attention. A phone number for the Bulletin Board to PMA 205-1H was given (800-472-4354). PC to PC correspondence can be sent through this number.

The world of technology is ever-changing and, when you relay these new technologies to the training community, innovative applications are developed and become the key to success. The objectives of this Expo were met and with continued government and industry support, the goals set forth by the Weapons Training 2000 Team.

Thanks go to the many individuals, and their supporting organizations, who have given so generously of their time and talents to make the third annual Airborne Weapons Technology Review and Training Exposition a success.

Joshua Johnson
Exhibition Chairman

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EXHIBITS

"GE Paperless Technical Manual"
General Electric

"Interactive Courseware Development"
Frontier Engineering, Inc.

"Computer Training Development"
ECC International Corporation

"PC Based Computer Training"
Delex Systems, Inc.

"ICW - System Intergration"
WICAT Systems

"Command, Control and Communications"
NCCOSC RDT&E Division

"Ocean Surveillance Systems"
NCCOSC RDT&E Division

"Weapons Simulation"
NSWC, Indian Head Division

"Emerging and Post-Production Systems"
NSWC, Indian Head Division

"Interactive Video/CBT"
Litton Guidance and Control Systems

"Ocular Tracking; Scenario Generator; Speech Conversion"
Naval Underwater Systems Center

"Computer Based Training: Laser & IR Maverick Missiles"
Ketron Division of The Bionetics Corporation

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TACTICAL COMBAT TRAINING SYSTEMS
(TCTS)
CONCEPT OF OPERATIONS
EXECUTIVE OVERVIEW

NOVEMBER 1991

BY

Larry Joy, PMA 248
and
Louis Medley, PMA 248

INTRODUCTION

This executive overview describes the concept of operations for the Tactical Combat Training System (TCTS), which will support Fleet tactical training and readiness evaluation. This overview, which follows the outline shown, first describes the purpose of the system and then offers a short discussion of the major shortfalls in current operational training suppose that are intended to be corrected by the TCTS. The operational performance requirements am then reviewed briefly before discussing the available technologies and instrumentation functional approach that make it feasible to develop a TCTS at this time. To further clarify the concept of operations, a graphic example is presented to show how the TCTS would be employed operationally in support of a Battle Group (BG) training exercise.

TCTS CONCEPT OF OPERATIONS--EXECUTIVE OVERVIEW
OUTLINE

PURPOSE

SHORTFALLS IN CURRENT OPERATIONAL TRAINING SUPPORT

REQUIREMENTS OVERVIEW

INSTRUMENTATION FUNCTIONAL APPROACH

EXAMPLE BATTLE GROUP (BG) TRAINING SCENARIO

SUMMARY

PURPOSE OF TCTS

The TCTS is required to satisfy two missions. The first is to enhance all aspects of current and projected naval combat training, and the second is to provide the data collection necessary for evaluating fleet exercises, developing tactics, and carrying out Operational Test and Evaluation (OP&E). Both missions are based upon the requirement that the Fleet exercise systems, conduct training, and evaluate warfighting effectiveness at sea. Therefore, the TCTS addresses unique at-sea training requirements independently from classroom and pierside training requirements; however, capabilities that are being developed separately to support coordinated multi-ship pierside training will be considered for use with TCTS at sea.

TCTS instrumentation will be designed to enhance naval combat training from single-platform warfighting performance through integration of multi-platform coordinated combat training (surface, subsurface, and air) and to include integrated Battle Group/Force multi-warfare training. To satisfy this purpose, TCTS instrumentation will be designed to provide accurate, realistic, and timely feedback of exercise activities without artificially constraining the exercise participants and with a minimum impact on participant support requirements (space and support personnel). Also, since units using TCTS may be deployed to remote (potentially hostile) locations for extended periods, the system will be designed so that it does not interfere with the operational effectiveness of the Fleet and so that it can be deployed at sea for long periods with minimal Fleet logistical support impact.

The instrumentation system developed to satisfy Fleet training requirements will also provide data for the evaluation of Battle Group readiness and tactical effectiveness, development of tactics, and operational test and evaluation of new systems prior to or after initial introduction into the Fleet.

PURPOSE OF TCTS

- ENHANCE NAVAL COMBAT TRAINING
  - *SINGLE PLATFORM TOTAL WARFIGHTING TRAINING*
  - *MULTI-PLATFORM COORDINATED COMBAT TRAINING*
  - *INTEGRATED BATTLE GROUP/FORCE MULTI-WARFARE TRAINING*

- COLLECT DATA TO SUPPORT THE ASSESSMENT OF:
  - *BATTLE GROUP READINESS*
  - *TACTICAL EFFECTIVENESS*
  - *TACTICS DEVELOPMENT*
  - *OT&E*

SHORTFALLS IN CURRENT TACTICAL TRAINING SUPPORT

The Navy trains its forces in all warfare areas using its weapons and sensor systems in as close a manner as possible to the way they would be employed in actual combat. The Navy's Tactical Training Range Roadmap documents various factors that severely limit the quality and effectiveness of that training:

Most at-sea tactical training is not validated since there is insufficient instrumentation available to support an objective assessment of training objective achievement. Monitoring of exercises is both limited and qualitative, and the lack of exercise data prevents timely effective training feedback.

Cost, safety, and security considerations prevent effective training in tactical weapons employment. Many sophisticated weapons are so expensive that the Fleet cannot afford to fire them except as required for weapon quality monitoring or test purposes. Even when the weapons are fired, the safety requirements associated with having actual weapons flyout, whether carrying explosive or dummy warheads, place significant constraints on the exercise which prevent training in realistic tactical employment of the weapon. Security considerations also limit realistic training employment of some weapon systems.

Most at-sea combat training is conducted without realistic threat representation. Targets are generally inadequate both in characteristics and numbers, particularly for threat air platforms, and the electronic warfare environments for training afloat are deficient in both quantity of threats and fidelity of the threat signatures. The cost of developing, procuring, and operating target and threat surrogates at sea remains prohibitive.

Normal training operating areas are not all supported by collocated fixed ranges. Thus, instrumented training capabilities are often out of reach of Fleet units requiring training support.

Inability to score strike training exercises conducted against realistic (uninstrumented) targets of opportunity located anywhere, prevents effective training in executing attacks directed at unfamiliar targets.

The lack of multi-Warfare training instrumentation that is deployable precludes adequate support of proficiency maintenance training for deployed forces. Warfare, skill levels achieved at one point of the training cycle (e.g., CV airwing strike warfare skills developed on the Fallon TACTS) become degraded during deployment.

Data collection to support Battle Group/Force evaluation is currently labor intensive, time-delayed, and has no adequate common reference (ground truth). The vast database of Battle Group actions and event outcomes is collected manually through system operator interviews and piecemeal compilation of existing data sources.

As a result of these major shortfalls, the current training capability does not enable the Fleet to train to the full capabilities of current weapons systems. However, available technology provides means to eliminate these shortfalls through the development of tactical training instrumentation.

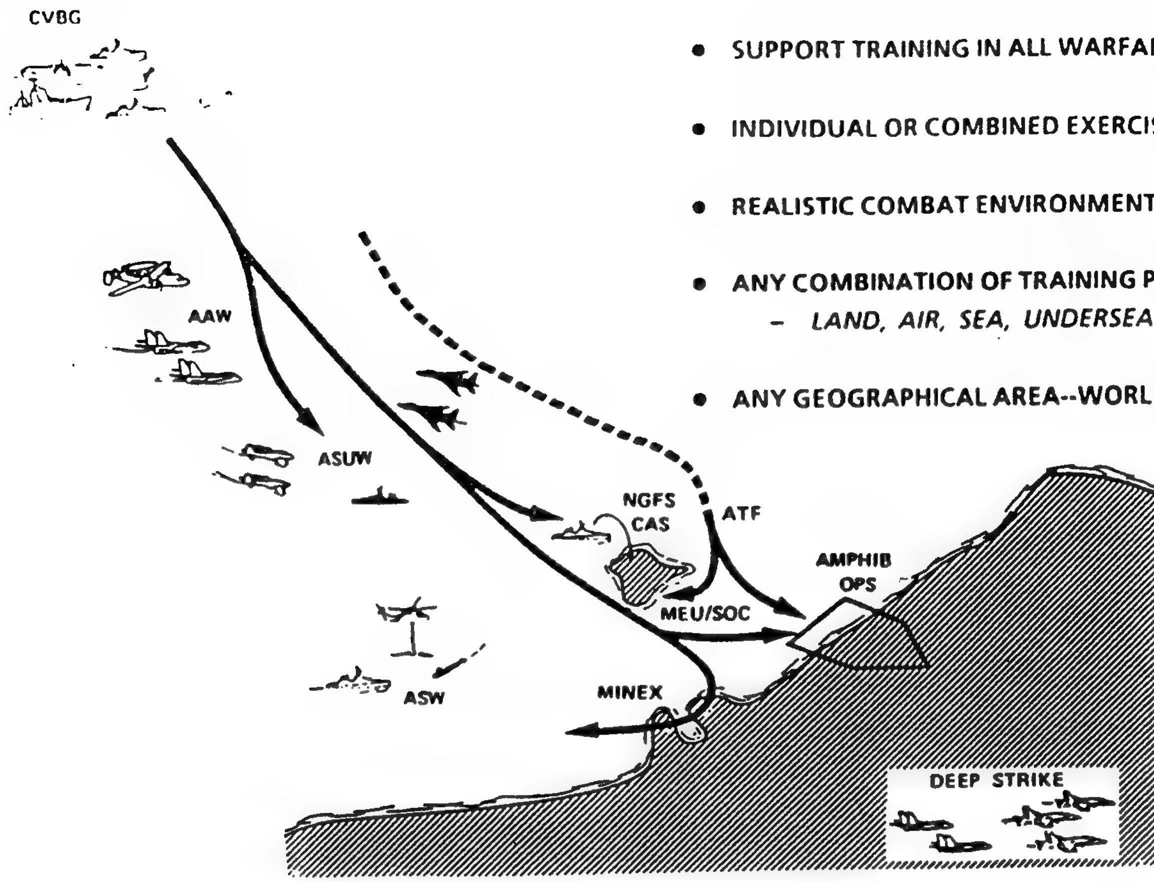
SHORTFALLS IN CURRENT TACTICAL TRAINING SUPPORT

- OBJECTIVE ASSESSMENT OF MOST TACTICAL TRAINING
  - *MONITORING CAPABILITY*
  - *TIMELY INTERACTIVE FEEDBACK*
- WEAPONS EMPLOYMENT TRAINING
  - *COST CONSIDERATIONS*
  - *SAFETY/SECURITY*
- REALISTIC THREAT REPRESENTATION
- ACCESSIBILITY OF INSTRUMENTED RANGES
- STRIKE ASSESSMENT AGAINST TARGETS OF OPPORTUNITY ANYWHERE
- PROFICIENCY TRAINING DURING DEPLOYMENT
- DATA COLLECTION FOR BATTLE GROUP/FORCE EVALUATION

TCTS OPERATIONAL PERFORMANCE REQUIREMENTS--OVERVIEW

The TCTS must support and enhance training in all warfare areas (including those pictured on this chart) by providing exercise reconstruction and timely feedback for either individual or combined warfare exercises. The TCTS also is required to provide a realistic combat environment, including realistic threats and exercise scenarios. TCTS instrumentation will be required to support any combination of training participants, including land, air, sea, and undersea platforms, and must be deployable to any geographical area, worldwide. The operational performance requirements are discussed in more detail in the next two charts.

TCTS OPERATIONAL PERFORMANCE REQUIREMENTS OVERVIEW



- SUPPORT TRAINING IN ALL WARFARE AREAS
- INDIVIDUAL OR COMBINED EXERCISES
- REALISTIC COMBAT ENVIRONMENT
- ANY COMBINATION OF TRAINING PARTICIPANTS
  - *LAND, AIR, SEA, UNDERSEA*
- ANY GEOGRAPHICAL AREA--WORLDWIDE

TCTS OPERATIONAL PERFORMANCE REQUIREMENTS

The TCTS must provide the tracking, data collection, secure data transmission, processing, and display necessary to conduct and assess tactical training. Data interface with combat systems on board all exercise participants will be critical to (1) collect the necessary data for performance evaluation and exercise monitoring, and (2) inject threat stimulation data into the combat systems during the exercise to increase tactical realism and provide immediate performance feedback.

The TCTS must provide timely feedback of training results to the exercise participants. This requires both real-time scoring sufficient to maintain battle realism and kill removal during interactive engagements and immediate post-operation reconstruction and debrief to all participants to get the greatest training value from each exercise.

Discussions with the Fleet also indicate a strong desire for the TCTS to be able to autonomously suppose training exercises involving scenarios up to Battle-Group size without needing shore-based assets or direct assistance.

The TCTS must be designed so that it will be deployable at sea in remote operational areas for long periods of time to provide proficiency training throughout the entire deployed period. The core instrumentation (hardware and software) must be highly portable and compact so it can be installed within available space(s) on any flag-configured ship. This portability will allow any Battle Group or Amphibious Ready Group to be equipped with TCTS to support all phases of at-sea exercises. The core instrumentation should also be configurable for installation at a fixed shore site. The TCTS should be designed to facilitate evolution to an organic system that can be embedded on every operational Fleet unit in the more distant future.

TCTS OPERATIONAL PERFORMANCE REQUIREMENTS

- PROVIDE TRACKING, DATA COLLECTION, SECURE DATA TRANSMISSION, PROCESSING & DISPLAY NECESSARY TO CONDUCT & ASSESS TACTICAL TRAINING

- FINISH TIMELY FEEDBACK OF TRAINING RESULTS TO PARTICIPANTS
  - *REAL-TIME SCORING & KILL REMOVAL*
  - *IMMEDIATE POST-OP REPLAY/DEBRIEF*

- PROVIDE AUTONOMOUS TRAINING CAPABILITY FOR EXERCISES UP TO BATTLE GROUP SIZE

- BE DEPLOYABLE TO SUPPORT WORLDWIDE NAVY TRAINING EXERCISES
  - *ALL TYPES OF TACTICAL TRAINING, OVER LAND AND/OR SEA*
  - *CAPABLE OF LONG-DURATION AT-SEA DEPLOYMENT CYCLES*
  - *HIGHLY PORTABLE & COMPACT*
  - *EVOLUTION TO AN EMBEDDED SYSTEM ON ALL NAVY SHIPS & AIRCRAFT*

TCTS OPERATIONAL PERFORMANCE REQUIREMENTS (Concluded)

The TCTS must be able to accommodate a mix of each possible threat representation in any desired combination to support a full range of at-sea training and BG evaluation exercises, including:

* Manned or unmanned platforms used to represent threat systems.

* Computer-generated simulated/stimulated pseudotargets and electromagnetic(EM) signals introduced into the operational sensors/displays of participant platforms to improve training realism (by increasing threat density).

* EM signal stimulation must be implemented so that it does not preclude reception of real-world signals of opportunity (e.g., radiating threat emitters and skin return from actual targets).

The TCTS must interface and exchange data with other ranges to provide interoperable capabilities. TCTS-equipped aircraft participants launched from carriers operating offshore must be able to fly strike training missions to an TACTS/ACMI-type ranges, including those located at NAS Fallon and Nellis AFB, Nevada. Aircraft participating in at-sea exercises can then take advantage of the fixed range capabilities, including scorable targets and Shrike, HARM, and EW training. The TCTS must also be able to exchange data with Fleet ranges (e.g., SCORE, AFWTF, and PMRF) whenever TCTS-equipped Fleet units are operating in their vicinity. TCTS will then be able to incorporate data collected by the fixed range systems (e.g. surveillance, EW training, and underwater tracking data), and the fixed ranges will be able to extend their surface and in-air instrumentation coverage using data from the TCTS.

TCTS instrumentation must be designed so that it does not constrain or limit the operational performance of training participants (operational ships and aircraft involved in training exercises). This will allow Fleet units deployed in remote areas to use the TCTS for day-to-day training and at the same time maintain full operational readiness. The main impacts of this requirement will be the need to ensure that training data are transmitted independently of Fleet tactical communications functions and that the approach used for tracking exercise participant positions does not constrain the tactical positioning of participating units as current systems do.

TCTS OPERATIONAL PERFORMANCE REQUIREMENTS

- ENHANCE THREAT REALISM BY SUPPORTING ANY MIX OF THREAT REPRESENTATIONS
  - *MANNED/UNMANNED THREAT PLATFORMS*
  - *SIMULATED THREAT PLATFORMS & EMITTERS (e.g., COMPUTER-GENERATED STIMULATION OF PARTICIPANT SENSOR SYSTEMS)*
  - *RADIATING THREAT EMITTERS*

- INTERFACE & EXCHANGE DATA WITH OTHER RANGES (INTEROPERABILITY)
  - *TACTS/ACMI TYPE RANGES (e.g., FALLON)*
  - *UNDERWATER RANGES AT SCORE, AFWTF, & PMRF*

- INSTRUMENTATION MUST NOT CONSTRAIN OPERATIONAL CAPABILITIES & TACTICS OF TRAINING EXERCISE PARTICIPANTS
  - *OPERATIONAL CAPABILITY OF PARTICIPANTS NOT DEGRADED BY INSTRUMENTATION*
  - *TRAINING DATA TRANSMISSION INDEPENDENT OF FLEET TACTICAL FUNCTIONS*
  - *TACTICAL SETUPS NOT CONSTRAINED BY INSTRUMENTATION*

INSTRUMENTATION FUNCTIONAL APPROACH--OVERVIEW

The development of TCTS is expected to use some technology previously proven by other training instrumentation systems. Additional development efforts in certain technical areas are complementary for TCTS and other programs; it is expected that these efforts will be pursued in a coordinated manner.

The Tactical Aircrew Combat Training System (TACTS) and Mobile Sea Range (MSR) programs have accomplished substantial development in areas directly transferrable to TCTS:

* Aircraft and ship interfaces--hardware and software needed to extract platform weapon and sensor system data, and to allow access for injecting signals into those systems.

* Instrumentation datalink--technology used for the MSR may have application to TCTS.

* Weapons simulations--computer-generated weapons flyout, threat representation models.

* Sensor stimulation--investigation of embedded sensor system simulators and stimulation techniques.

* Datalink encryption--COMSEC device and techniques developed for TACTS and MSR are directly applicable to the datalink security requirements of TCTS.

The Battle Force Tactical Training (BFTT) program also requires ship interfaces and ship sensor system stimulation technology. Development of common interfaces for BFTT and TCTS is a program goal.

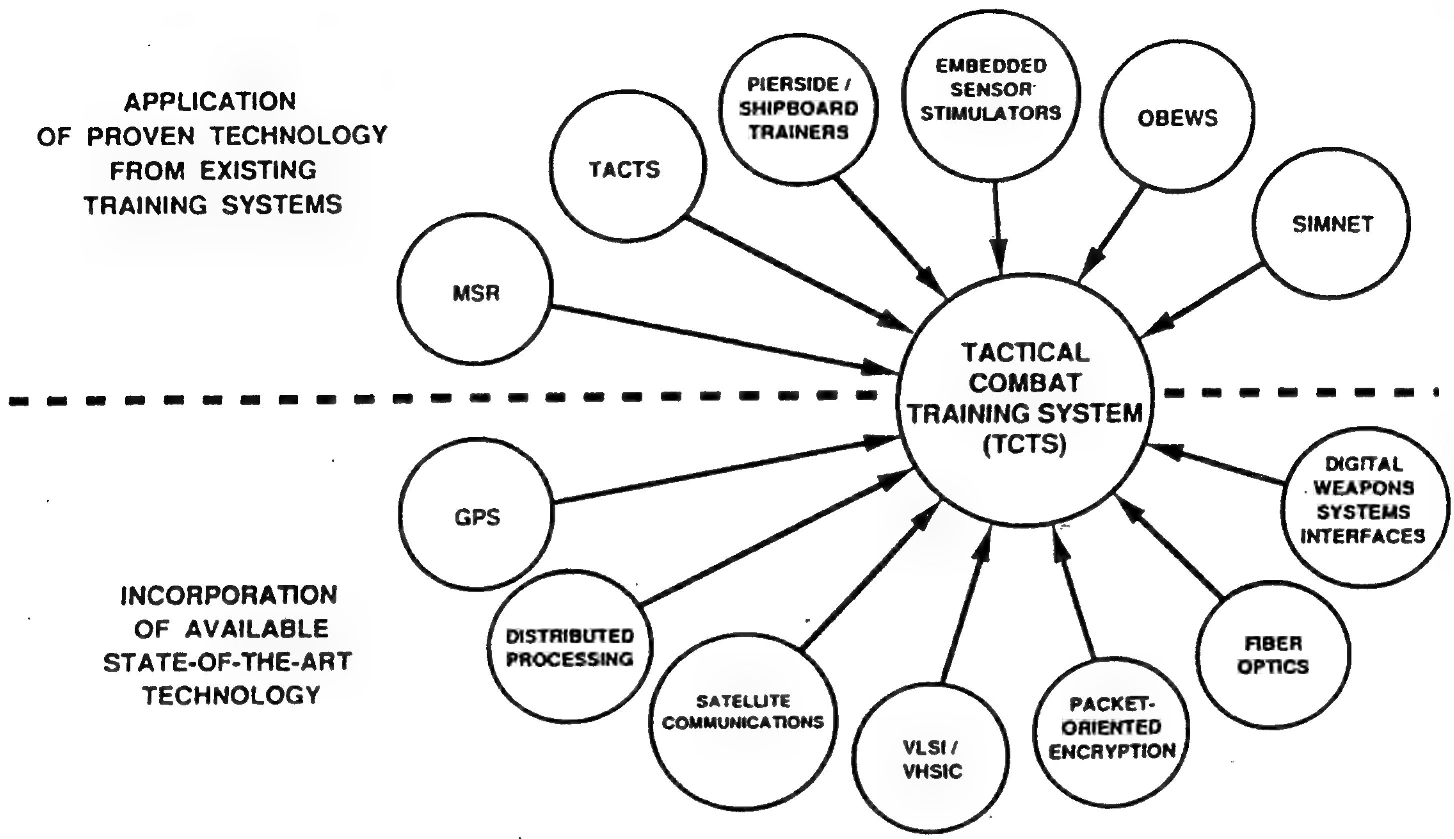
Development of upgraded airborne instrumentation subsystem (UPOD) common participant instrumentation equipment (in pod and internal configurations) for general training instrumentation applications (including TACTS/ACMI and MSR) is an important complementary program that will contribute to TCTS goals.

The Global Positioning System (GPS), which will provide accurate participant position data and timing independent of fixed sites, has the demonstrated potential to provide the TCTS tracking base.

Available state-of-the-art technology will provide many advanced capabilities and dramatic improvements in performance/size ratios of products that can be incorporated into TCTS hardware subsystems.

INSTRUMENTATION FUNCTIONAL APPROACH

APPLY PROVEN & AVAILABLE TECHNOLOGY TO OVERCOME SHORTFALLS



INSTRUMENTATION FUNCTIONAL APPROACH

The instrumentation functional approach for the TCTS builds upon proven training systems through the addition of currently available state-of-the-art technology. The principal functions required of the TCTS are:

Position location, tracking, and time synchronization of all exercise participants

Interface(s) with exercise participants to collect/inject warfare systems status and event data

Data transmission capacity for necessary exercise data collection, interaction (e.g., kill removal), and timely training feedback

Coordinated/distributed data processing capability to support realistic interactive exercises

Display and debrief capability to conduct and evaluate multiwarfare exercises.

The TCTS functional approach in each of these areas is addressed in subsequent charts.

INSTRUMENTATION FUNCTIONAL APPROACH
REQUIREMENTS

- POSITION LOCATION, TRACKING, & TIME SYNCHRONIZATION OF ALL EXERCISE PARTICIPANTS

- INTERFACE(s) WITH EXERCISE PARTICIPANTS TO COLLECT/INJECT WARFARE SYSTEMS STATUS & EVENT DATA

- DATA TRANSMISSION CAPACITY FOR NECESSARY EXERCISE DATA COLLECTION, INTERACTION (e.g., KILL REMOVAL) & TIMELY TRAINING FEEDBACK

- COORDINATED/DISTRIBUTED DATA PROCESSING CAPABILITY TO SUPPORT REALISTIC INTERACTIVE EXERCISES

- DISPLAY & DEBRIEF CAPABILITY TO CONDUCT & EVALUATE MULTIWARFARE EXERCISES

POSITION LOCATION, TRACKING, AND TIME SYNCHRONIZATION

Position location, tracking, and time synchronization will be accomplished using an integrated approach employing Global Positioning System (GPS) data from all participants supplemented with attitude, angular rates, and acceleration data obtained from inertial units to accomplish state-vector tracking of those aircraft engaged in high-dynamics maneuvering.

The GPS and inertial data will be acquired from participant platform organic GPS and inertial units whenever feasible. For participants not equipped with organic GPS receivers or inertial units, GPS and/or inertial equipment will be provided as part of the platform's TCTS instrumentation.

Time synchronization will be accomplished in each participant's TCTS instrumentation unit using the accurate timing data provided by GPS. Each participant's state-vector data will be time-tagged by the TCTS instrumentation unit and transmitted to the TCTS core instrumentation in near-real time via the TCTS instrumentation datalink.

Submarine position data will be collected from one of two sources: either post-event from the onboard tactical inertial navigation system; or in near-real time from fixed or portable underwater range acoustic tracking systems if exercise location permits.

INSTRUMENTATION FUNCTIONAL APPROACH

POSITION LOCATION, TRACKING, & TIME SYNC

- TRACK ALL SURFACE & AIR EXERCISE PARTICIPANTS USING POSITION/VELOCITY DATA OBTAINED FROM GLOBAL POSITIONING SYSTEM (GPS) UNITS ON EACH PARTICIPANT

- SUPPLEMENT GPS DATA WITH STATE-VECTOR DATA (ATTITUDE, ANGULAR RATES, & ACCELERATION) OBTAINED FROM INERTIAL UNITS ON SELECTED HIGH-DYNAMICS AIRCRAFT PARTICIPANTS

- ACQUIRE GPS & INERTIAL DATA FROM PARTICIPANT PLATFORMS' ORGANIC TACTICAL GPS & INERTIAL UNITS WHENEVER FEASIBLE (USUALLY VIA INTERFACE WITH ONBOARD DATA BUSES)
  - *PROVIDE GPS/INERTIAL UNITS AS PART OF TCTS INSTRUMENTATION (PODS OR INTERNAL UNITS) FOR PARTICIPANTS NOT EQUIPPED WITH ORGANIC TACTICAL GPS/INERTIAL UNITS*

- SYNCHRONIZE EACH PARTICIPANT WITH GPS TIME BASE

- TRANSMIT TIME-TAGGED GPS/INERTIAL DATA FROM PARTICIPANTS TO TCTS CORE INSTRUMENTATION IN NEAR-REAL TIME VIA TCTS INSTRUMENTATION DATALINK

- RECEIVE POST-EVENT TRACK DATA OBTAINED FROM SUBMARINES' ONBOARD TACTICAL INERTIAL NAVIGATION SYSTEMS & INTEGRATE INTO TCTS CORE INSTRUMENTATION IN NON-REAL TIME
  - *INCORPORATE NEAR-REAL-TIME TRACK DATA FROM FIXED OR PORTABLE UNDERWATER RANC WHEN TCTS OPERATIONS ARE CONDUCTED IN THEIR VICINITY*

INTERFACES WITH EXERCISE PARTICIPANTS

Interfaces with exercise participants are required to capture the warfare systems status and event data necessary for exercise evaluation and management and to provide for data injection to simulate platform tactical systems. TCTS will take advantage of existing aircraft and ship interfaces and those under development for other programs including: aircraft and ship interfaces developed for the TACTS/ACMI and MSR programs, pierside ship combat system training interfaces, and shipboard embedded training system interfaces. A continuing program to introduce platform training interface standards to guide design of new ship and aircraft systems is recommended.

INSTRUMENTATION FUNCTIONAL APPROACH

INTERFACES WITH EXERCISE PARTICIPANTS

- MAKE MAXIMUM USE OF EXISTING DATA CAPTURE/DATA INJECTION INTERFACES & THOSE UNDER DEVELOPMENT:
  - *TACTS/ACMI*
  - *MSR*
  - *PIERSIDE SHIP COMBAT SYSTEM TRAINERS*
  - *STIMULATORS/TRAINERS EMBEDDED IN COMBAT SYSTEMS*

- DEVELOP NEW INTERFACES AS REQUIRED

- DEVELOP RECOMMENDED PLATFORM TRAINING INTERFACE STANDARDS TO GUIDE DESIGN OF NEW SHIP & AIRCRAFT SYSTEMS
  - *COORDINATED WITH OTHER TRAINING INTERFACE USER REQUIREMENTS*
  - *EVOLUTION TO NAVY-WIDE AND/OR DoD TRAINING INTERFACE STANDARDS*

TCTS INTERFACE WITH EXISTING SHIPBOARD-EMBEDDED TRAINING SYSTEMS

Embedded training systems will be in place as organic equipment on many combatant ship classes during the 1990s. These systems include the AN/USQ-93(V) Radar Environment Simulator System (RESS), the Advanced Combat Direction System (ACDS) Shipboard Training and Assessment Group (STRAG), the Aegis Combat Training System (ACTS), the AN/SSQ-91(V) Combat Simulation Test System (CSTS), and the AN/SQQ-89T(V) On-Board Trainer (OBI). Each of these embedded training systems will interface with various shipboard tactical systems installed on specific ship classes. These training interfaces will provide for stimulation of tactical sensor and combat systems by the embedded trainer and for monitoring/collection of data from the tactical systems.

TCTS will make use of these available stimulation and data monitoring capabilities by interfacing with a ship's embedded training system rather than with the multiple tactical systems individually. TCTS will coordinate the activities of the simulators in real time so that the shipboard sensor systems are stimulated appropriately in consonance with the dynamic TCTS training scenario. The TCTS instrumentation unit will consolidate data collected from shipboard tactical systems via the embedded training system and transfer data to the TCTS core instrumentation (and other participants as necessary) via the TCTS instrumentation datalink.

TCTS WILL INTERFACE WITH EXISTING SHIPBOARD EMBEDDED TRAINING SYSTEMS

EMBEDDED TRAINING SYSTEM	SENSOR SYSTEMS THAT ARE STIMULATED	APPLICABLE SHIPS
AN/USQ-93(V) RADAR ENVIRONMENT SIMULATOR SYSTEM (RESS)	TRACKING & SURVEILLANCE RADAR/IFF (RF), EW (GROWTH)	NEW THREAT UPGRADE SHIPS: ALL NON-AEGIS CRUISERS & KIDD CLASS DESTROYERS (32 SHIPS)
ADVANCED COMBAT DIRECTION SYSTEM/SHIPBOARD TRAINING & ASSESSMENT GROUP (ACDS/STRAG)	BLOCK I PLANS: TRACKING & SURVEILLANCE RADAR/IFF, ASW, EW (USING RESS & SM-441)	VARIOUS CV/CVN, CG/CGN, & DD/DDG (POTENTIALLY OVER 150 SHIPS BY LATE 1990s)
AEGIS COMBAT TRAINING SYSTEM (ACTS)	AN/SPY-1 RADAR/IFF (ASW WHEN INTEGRATED WITH OBT)	ALL AEGIS CRUISERS & DESTROYERS (30 SHIPS BY MID-1990s)
AN/SSQ-91(V), COMBAT SIMULATION TEST SYSTEM (CSTS)	TRACKING & SURVEILLANCE RADAR/IFF USING RF & VIDEO MIX (CSTS STIMULATORS & SM-441)	LHD-1 CLASS (6 SHIPS)
AN/SQQ-89T(V), ON-BOARD TRAINER (OBT)	ASW, DIGITAL STIMULATION OF EW (ALQ-142 & SLQ-32 ESM)	AEGIS CRUISERS & DESTROYERS; KIDD & SPRUANCE CLASS DESTROYERS; PERRY CLASS FRIGATES (APPROX. 120 SHIPS)

DATA TRANSMISSION

Exercise data transmission requirements will be satisfied by providing secure instrumentation datalink capabilities between the TCTS core (master processor) instrumentation and all participants and by employing long-range wideband datalink capabilities to interconnect the core, shore support facility(s), fixed ranges, and remote debriefing sites afloat and ashore.

A real-time RF datalink will allow basic instrumentation data exchange between the core instrumentation and all surface and airborne participants. The datalink must be independent of Fleet tactical functions to avoid loading tactical links with TCTS instrumentation traffic. Frequency selection should avoid bands that might be jammed during exercises.

This datalink must be encrypted for data security and designed to allow interparticipant communications to be conducted between nearby participants during detached operations when connectivity with the core instrumentation is interrupted.

Two approaches are currently under consideration for submarine post-event data transmission: data transmission from communications depth (e.g., via satellite relay channel), and use of a SLOT-buoy type device (e.g., AN/BRT-6 SATCOM buoy) that, after being loaded with data and released from operating depth, will rise to the surface and transmit the data via the SSIXS channel.

Satellite links (either leased or government) will permit data transmission between the core instrumentation and distant facilities to support large multiforce exercises, relay readiness evaluation data for analysis, interface with fixed ranges, and support exercise debriefs at remote sites.

INSTRUMENTATION FUNCTIONAL APPROACH

DATA TRANSMISSION

- RF DATALINK BETWEEN CORE INSTRUMENTATION & AIR/SURFACE PARTICIPANTS
  - *INDEPENDENT OF TACTICAL FUNCTIONS*
    - AVOID LOADING TACTICAL LINKS WITH INSTRUMENTATION TRAFFIC
    - AVOID JAMMING TARGETED AT TACTICAL COMM, RADAR, & DATALINKS
  - *END-TO-END ENCRYPTION FOR DATA SECURITY*
  - *DATA TRANSMISSION IN NEAR-REAL TIME FOR AIR & SURFACE PARTICIPANTS*

- POST-EVENT DATA TRANSMISSION FOR SUBSURFACE PARTICIPANTS

- SATELLITE LINKS BETWEEN CORE INSTRUMENTATION & SHORE SUPPORT FACILITY(s)/FIXED RANGES/REMOTE DEBRIEF SITES (AFLOAT & ASHORE)

COORDINATED/DISTRIBUTED DATA PROCESSING

TCTS will employ a distributed architecture in which each participant's onboard TCTS instrumentation package must perform extensive local data processing functions that are coordinated with the overall training scenario. Current state-of-the-art microprocessor technology can provide the processing throughput necessary to execute these functions locally and to coordinate with other participants and the TCTS core instrumentation.

INSTRUMENTATION FUNCTIONAL APPROACH

COORDINATED/DISTRIBUTED DATA PROCESSING

- **DISTRIBUTED PARTICIPANT INSTRUMENTATION UNIT HARDWARE/SOFTWARE WITH CAPACITY TO:**
  - *MONITOR CURRENT OWNSHIP POSITION, HEADING, etc.*
  - *MONITOR POSITION REPORTS FROM OTHER NEARBY (REAL) PARTICIPANTS*
  - *SIMULATE LOCAL THREAT ENVIRONMENT (PER THREAT SCENARIO DATABASE) & GENERATE STIMULATION PARAMETERS FOR INJECTION INTO PARTICIPANT SENSOR & WEAPON SYSTEMS*
  - *CORRELATE PARTICIPANT'S TARGET TRACKS WITH REFERENCE TRACK INFORMATION (SIMULATED OR REAL)*
  - *PERFORM WEAPON/COUNTERMEASURES EMPLOYMENT EFFECTS ASSESSMENT (e.g., MISSILE FLYOUT SIMULATION) & PROVIDE FEEDBACK TO PARTICIPANTS*
  - *ARCHIVE & DOWNLINK (TO CORE INSTRUMENTATION) CRITICAL INFORMATION TO SUPPORT DEBRIEF & PERFORMANCE ASSESSMENT*

CENTRALIZED DATA PROCESSING

TCTS instrumentation installed on ships will incorporate the core instrumentation functions needed to coordinate and monitor database generation and distribution, exercise execution, data correlation, debrief database generation and dissemination, and data interchange with remote facilities afloat and ashore. One ship will be designated to perform the core instrumentation functions for each specific exercise. It also will be possible to configure fixed shore sites to perform the core instrumentation functions for exercises in their vicinity.

INSTRUMENTATION FUNCTIONAL APPROACH

CENTRALIZED DATA PROCESSING

- SHIPS CONFIGURED TO SUPPORT CORE INSTRUMENTATION FUNCTIONS:
  - *GENERATE SIMULATED THREAT SCENARIO DATABASE & DISTRIBUTE SUBSETS TO EACH PARTICIPANT PRIOR TO EXERCISE START*
  - *MODIFY THREAT SCENARIO DATABASE DURING EXERCISE (IN RESPONSE TO OPERATOR ENTRIES) & DISTRIBUTE CHANGES TO AFFECTED PARTICIPANTS*
  - *MAINTAIN POSITION & MOTION STATE-VECTOR LOG ON ALL PARTICIPANTS*
  - *CORRELATE POSITION DATA WITH TARGET TRACKING, STATUS, & EVENT DATA COLLECTED FROM PARTICIPANT SENSORS & WEAPON SYSTEMS*
  - *GENERATE CONSOLIDATED DEBRIEFING DATABASE*
  - *PRE-PROCESS PERFORMANCE ASSESSMENT INFORMATION FOR TRANSMISSION TO SHORE FACILITY(s)*

- FOR EACH SPECIFIC EXERCISE, ONE SHIP WILL BE DESIGNATED TO PERFORM THE CORE INSTRUMENTATION FUNCTIONS

- FIXED SHORE SITES CAN ALSO BE CONFIGURED TO PERFORM CORE INSTRUMENTATION ROLE

DISPLAY AND DEBRIEF CAPABILITY

Display and debrief are required to take full advantage of the extensive training and assessment capabilities of the TCTS. Display capabilities are necessary for performing shipboard core instrumentation and operating/debriefing functions and for interfacing with display equipment at fixed shore sites for debriefing and exercise assessment and evaluation.

The latest NDI technology is considered satisfactory for development of the portable operating and debriefing stations needed aboard ships for training exercise coordination and debriefing. These displays will be highly portable, rugged, and compact, suitable for the most flexible installation in very restricted shipboard space(s). Interfaces also will be provided to permit the use of compatible embedded shipboard operational displays for debrief of TCTS-supported exercises and for displaying data received from fixed ranges at shipboard operating/debriefing stations.

Interfaces for data exchange with fixed-range and shore support facility display systems will be developed to provide for remote debriefing and optional shore-based coordination support for large-scale exercises, and to provide assessment data in support of post-exercise Battle Group evaluation and assessment by Fleet analysts.

INSTRUMENTATION FUNCTIONAL APPROACH

DISPLAY & DEBRIEF CAPABILITY

- USE LATEST NDI DISPLAY TECHNOLOGY (e.g., TAC-III) TO PROVIDE PORTABLE OPERATING/DEBRIEFING STATIONS(s) THAT CAN BE FLEXIBLY CONFIGURED & DISTRIBUTED IN SHIPBOARD OPERATING SPACES
  - *MULTIPLE STATIONS FOR CORE INSTRUMENTATION EXERCISE SETUP, MONITORING, CONTROL, & DEBRIEF*
  - *OPERATING/DEBRIEFING STATION(s) FOR OTHER SHIP PARTICIPANTS*
- SHIPBOARD INTERFACES TO ALLOW USE OF OPERATIONAL DISPLAYS (e.g., UYQ-21) FOR POST-EXERCISE DEBRIEFING
- CAPABILITY TO DISPLAY DATA RECEIVED FROM FIXED RANGES AT SHIPBOARD OPERATING/DEBRIEFING STATIONS
- REMOTE DEBRIEFING AT EXISTING SHORE FACILITIES (e.g.,TACTS, FIXED RANGES) THROUGH TCTS INTERFACES TO EXISTING DISPLAY SYSTEM(s)
- INTERFACES WITH SHORE SUPPORT FACILITY DISPLAYS FOR OPTIONAL EXERCISE COORDINATION SUPPORT & FOR POST-EXERCISE BATTLE GROUP EVALUATION & ASSESSMENT SUPPORT

TCTS TOP-LEVEL NOTIONAL DESIGN

The top-level TCTS notional design illustrated below indicates the basic system elements and interfaces necessary to satisfy the TCTS concept of operations. A few basic elements form the design--participant instrumentation for ship and aircraft installation, the core instrumentation functions to be exercised by a participating ship or at a fixed site, interfaces with fixed ranges for two-way data interchange, optional interfaces and debriefing equipment for installation at shore-based training simulator facilities, optional debriefing equipment (installable at either ship or shore sites for remote debriefing), and interfaces with shore support facilities. All of these elements are readily achievable using current technology.

* Participant instrumentation consists of a GPS receiver to determine position and time, interfaces and monitoring equipment to collect the sensor/weapons/C^3 data during each exercise, and stimulation interfaces and processing needed to exercise participant equipment as directed by the core system. A local processor is needed to adapt the commands and data from the core system to the participant and to perform distributed processing. A transceiver is required to communicate with the core instrumentation (and other participants) over a fully secure datalink. A small portable display/debriefing station is envisioned for individual ship participants.

* The core instrumentation functions, which ships and fixed ranges can be configured to perform, include processing and display for setting up, controlling, and debriefing the entire training exercise. In addition, the core instrumentation is expected to manage a satellite communications terminal to connect the deployed TCTS system with shore facilities. However, the core instrumentation and participating aircraft/ships will be capable of completely autonomous operations when not in communication with shore facilities. All datalinks will be fully encrypted and secure.

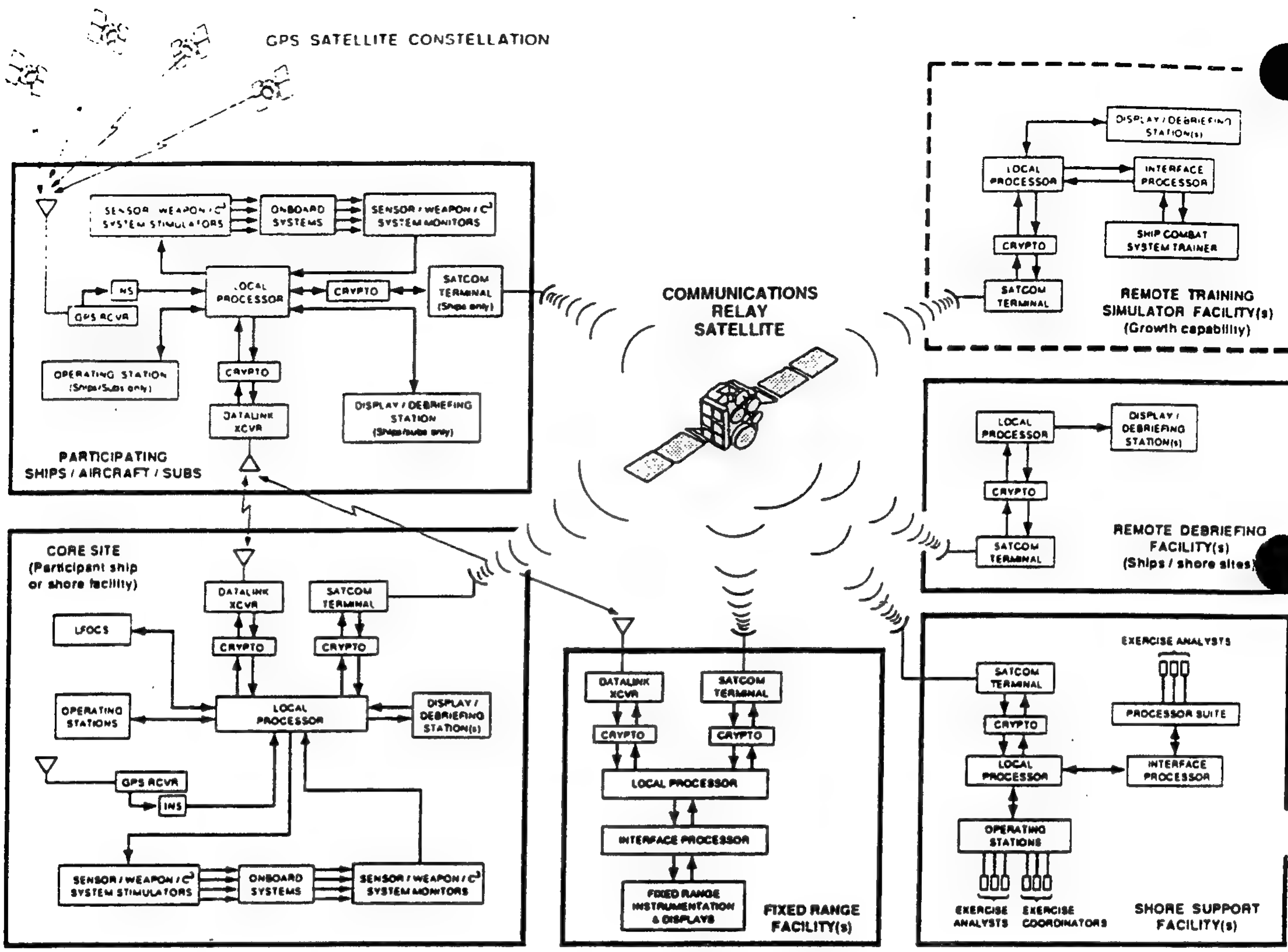
* Interfaces with fixed range facilities (e.g., Fallon TACTS, SCORE, AFWTF, PMRF) are included in the design to allow data to be exchanged between them and the TCTS core instrumentation via communications satellite for display on any system. TCTS data could be provided to the fixed ranges and data from the fixed ranges could be displayed at sea.

* Interfaces with shore-based training simulator facilities are included as a growth capability to support their future integration into TCTS-supported exercises and participation in subsequent debriefing.

* Remote debriefing facilities are included in the design to allow exercise data to be displayed at any desired remote location and for more convenient debriefing of distant exercise participants as required.

* Interfaces with a shore support facility are also included in the design. The shore support facility(s) would contain processing and display systems necessary to support both exercise coordination (for large, multiforce exercises) and exercise analysis (for Fleet readiness and Battle Group effectiveness evaluation).

TCTS TOP-LEVEL NOTIONAL DESIGN



EXAMPLE TCTS BATTLE GROUP TRAINING SCENARIO

To illustrate the concept of operations for employment of the TCTS to support enhanced combat training at sea, an example Battle Group training scenario is presented. The principal functions to be performed by the major elements of the TCTS are described for the pre-mission system initialization, mission operations, and post-mission debrief phases of the training. The example training exercise involves simultaneous ASUW and ASW operations conducted by a CV Battle Group. The TCTS core instrumentation is located aboard the CV. Alteratively, the core instrumentation could be located aboard another flag-configured ship. Each participating ship and aircraft is equipped with an onboard TCTS instrumentation unit.

Initialization

Prior to commencement of the exercise, the training officer interacts with the TCTS core instrumentation to set it up for the planned exercise operations. Appropriate ASUW and ASW missions/scenarios are called up from the stored TCTS database, and they are modified combined, and tailored to incorporate the specific target platform configurations, threat system characteristics, and weapons loadings that must be simulated by the TCTS to meet the training objectives of this exercise. As necessary, new mission/scenario parameters are generated and entered into the database.

As exercise operations begin, the TCTS core instrumentation automatically establishes secure two-way data communications with each participant's onboard TCTS instrumentation unit via the instrumentation datalink. Once TCTS datalink connectivity is established with each participant, the core instrumentation uploads that participant's mission/scenario parameter database (targets, threats, weapons, etc.) to the participant's onboard instrumentation unit. Since the TCTS datalink is fully encrypted, the individual participant databases that are uploaded over the air can include classified information.

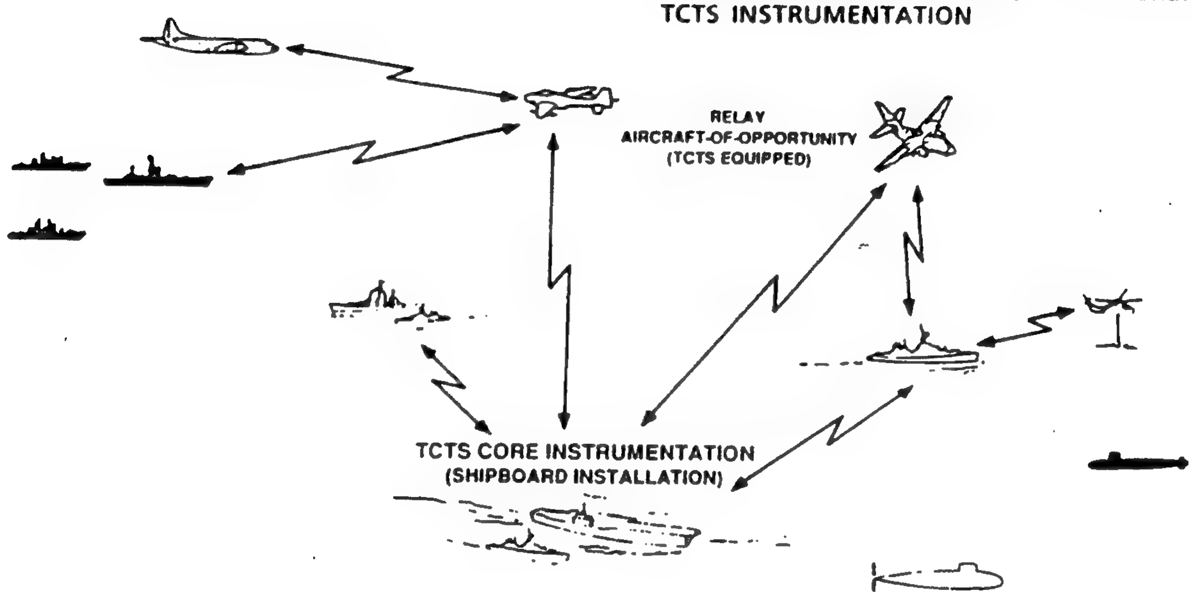
At COMEX, the exercise proceeds without interference from the TCTS instrumentation, which performs its functions and manages its interfaces with participants automatically. The crews aboard exercise participants perform their normal tactical functions; no additional interactions with TCTS instrumentation are required.

EXAMPLE TCTS BATTLE GROUP TRAINING SCENARIO
INITIALIZATION

- BEFORE EXERCISE BEGINS, TRAINING OFFICER INTERACTS WITH TCTS CORE INSTRUMENTATION:
  - *IDENTIFIES DESIRED MISSION/SCENARIO*
  - *MODIFIES/TAILORS DATABASE PARAMETERS TO SUIT SPECIFIC TRAINING OBJECTIVES*

- TCTS CORE INSTRUMENTATION:
  - *ESTABLISHES SECURE DATALINK CONNECTIVITY WITH EACH EXERCISE PARTICIPANT*
  - *UPLOADS MISSION/SCENARIO PARAMETER DATABASE (TARGETS, WEAPONS, THREATS, etc) TO EACH PARTICIPANT'S ONBOARD TCTS INSTRUMENTATION UNIT*

- EXERCISE PROCEEDS WITHOUT INTERFERENCE FROM TCTS INSTRUMENTATION



Surface and Airborne Exercise Participant Operations

As the Battle Group ships and aircraft pursue their assigned tactical missions (e.g., the ASUW operation is illustrated), each participation onboard TCTS instrumentation unit continuously acquires position data either from the platform's organic GPS receiver (if one is installed) or from a GPS receiver incorporated in the instrumentation unit. TCTS instrumentation units also perform a similar function aboard any participating air or surface platforms that are employed in the exercise to act as ORANGE Force threat elements. When a simulated threat ship or aircraft enters the coverage of a BLUE participant, that participant's TCTS instrumentation unit stimulates its tactical sensors and combat systems with targets, threats, and EW in accordance with the training scenario database stored in the instrumentation unit. When a "real" threat platform (i.e., an aircraft or ship that is emulating a specified adversary platform type) enters the coverage of a BLUE participant, that participant's TCTS instrumentation unit stimulates its tactical systems that are not realistically simulated by the adversary platform and its onboard equipment. The TCTS instrumentation unit also monitors GPS-based position reports transmitted over the TCTS interparticipant datalink by other nearby exercise participants and correlates targets identified by ownship tactical sensors and weapons systems with TCTS reference tracks (both GPS-based real tracks and scenario-driven simulated tracks). The instrumentation unit runs real-time simulations to evaluate the outcome of any weapon employment events initiated by the BLUE ship or aircraft crew and provides feedback assessment (e.g., kill/no-kill) to the crew. It also assesses the results of any countermeasures employed by the crew against simulated threats and modifies the stimulation characteristics accordingly.

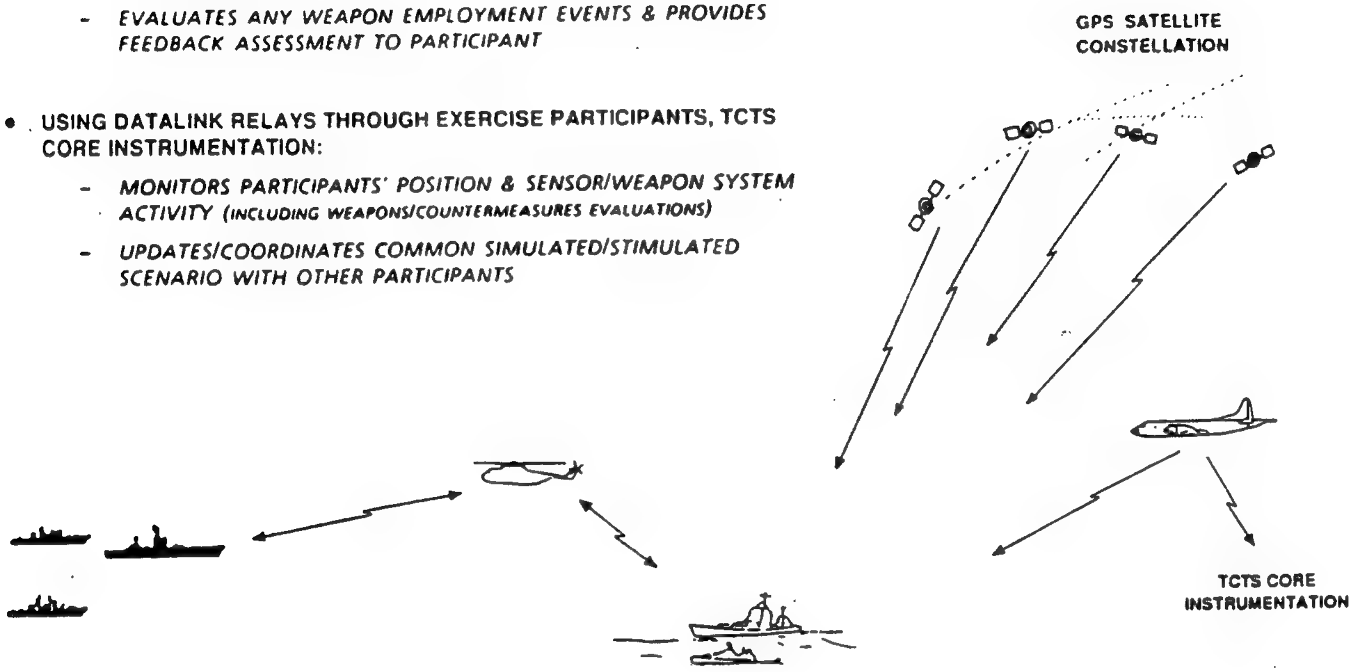
Using multiple datalink relays through TCTS-equipped participants within mutual RF line-of-sight, the TCTS core instrumentation monitors participants' positions and sensor/weapon system activity (including stimulation, weapons simulation, and evaluation of results) via downlink exercise data messages. The core instrumentation updates the BLUE participants' onboard scenario databases (e.g., deletion of threat elements evaluated as destroyed by other participants) via uplink messages to accomplish dynamic real-time coordination of the ongoing simulated/stimulated mission scenario among all the exercise participants.

The progress of the mission can be observed in real rime it the TCTS core instrumentation monitoring/control station. Throughout the mission, the core instrumentation stores exercise data for use in post-exercise replay and debrief.

EXAMPLE TCTS BATTLE GROUP TRAINING SCENARIO
SURFACE & AIRBORNE EXERCISE PARTICIPANT OPERATIONS

- EACH PARTICIPANT'S ONBOARD TCTS INSTRUMENTATION UNIT:
    - *DETERMINES PARTICIPANT'S GPS BASED POSITION*
    - *MONITORS POSITION REPORTS FROM OTHER NEARBY PARTICIPANTS*
    - *STIMULATES PARTICIPANT'S SENSORS WITH TARGETS, THREATS, & EW PER TRAINING SCENARIO*
    - *CORRELATES OWNSHIP TARGET IDs WITH REFERENCE TRACKS (REAL & SIMULATED)*
    - *EVALUATES ANY WEAPON EMPLOYMENT EVENTS & PROVIDES FEEDBACK ASSESSMENT TO PARTICIPANT*

- USING DATALINK RELAYS THROUGH EXERCISE PARTICIPANTS, TCTS CORE INSTRUMENTATION:
    - *MONITORS PARTICIPANTS' POSITION & SENSOR/WEAPON SYSTEM ACTIVITY (INCLUDING WEAPONS/COUNTERMEASURES EVALUATIONS)*
    - *UPDATES/COORDINATES COMMON SIMULATED/STIMULATED SCENARIO WITH OTHER PARTICIPANTS*



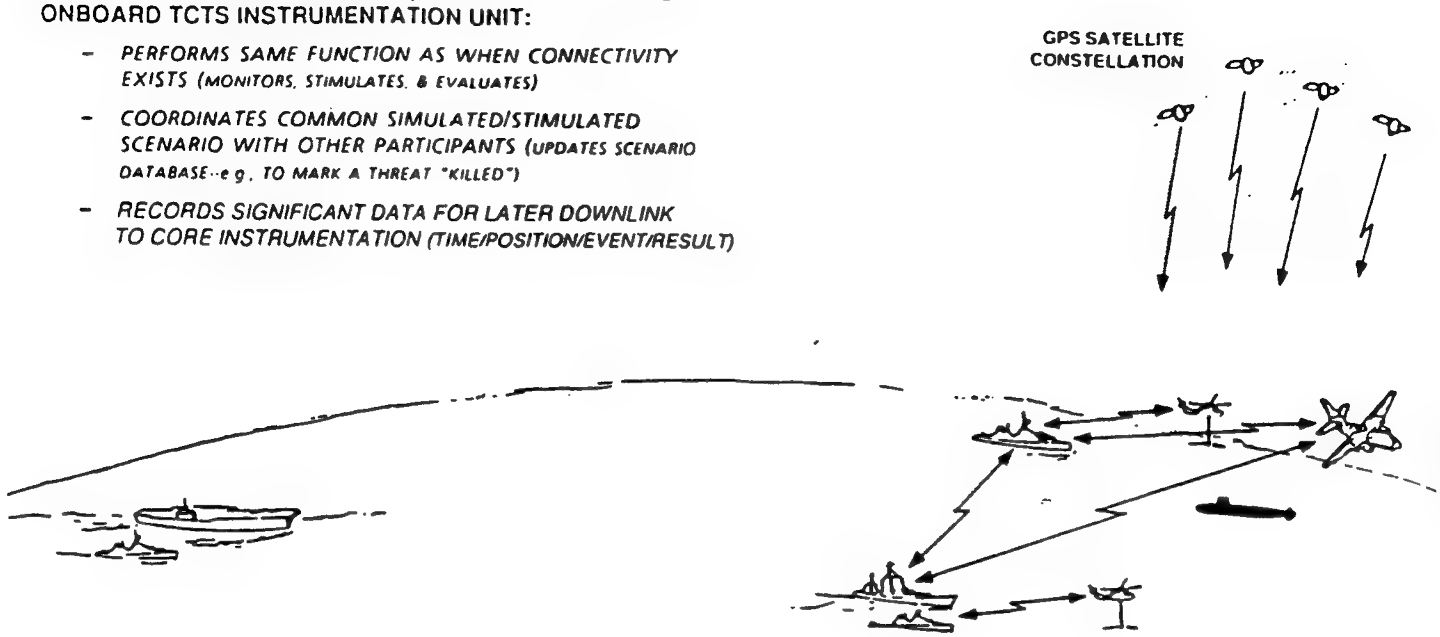
Detached Cluster Operations

Some exercise missions will involve BLUE Force participant operations in areas where insufficient relay paths exist to maintain continuous TCTS datalink connectivity with the core instrumentation (e.g., outer-zone ASW operations are illustrated). However, each participant's onboard TCTS instrumentation unit performs the position and event monitoring, stimulation, weapon simulation, and evaluation functions described previously. Interparticipant communications via the TCTS secure datalink are used to accomplish dynamic real-time coordination of the simulated/stimulated mission scenario within the detached cluster of participants. If real targets or signals are present, they will also be processed by participants' tactical sensors and combat systems; the TCTS stimulation techniques do not preclude detection and acquisition of real targets by the sensors and combat systems being stimulated.

While operating beyond datalink connectivity with the core instrumentation, each onboard TCTS instrumentation unit stores significant mission exercise data (time-tagged positions, events, stimulation/simulation/weapons data, and evaluation results) for later downlink transmission to the core instrumentation when TCTS datalink connectivity is reestablished.

EXAMPLE TCTS BATTLE GROUP TRAINING SCENARIO
DETACHED CLUSTER OPERATIONS

- WHEN BEYOND DATALINK CONNECTIVITY WITH TCTS CORE INSTRUMENTATION, EACH PARTICIPANT'S ONBOARD TCTS INSTRUMENTATION UNIT:
  - *PERFORMS SAME FUNCTION AS WHEN CONNECTIVITY EXISTS (MONITORS, STIMULATES, & EVALUATES)*
  - *COORDINATES COMMON SIMULATED/STIMULATED SCENARIO WITH OTHER PARTICIPANTS (UPDATES SCENARIO DATABASE--e.g., TO MARK A THREAT "KILLED")*
  - *RECORDS SIGNIFICANT DATA FOR LATER DOWNLINK TO CORE INSTRUMENTATION (TIME/POSITION/EVENT/RESULT)*



- STIMULATION METHOD DOES NOT PRECLUDE ONBOAR SENSORS' ABILITY TO ACQUIRE REAL TARGETS

Data Retrieval from Submarines

When submarines participating in TCTS-supported exercises operate within the instrumentation coverage of fixed underwater ranges, * real-time three-dimensional track data are available for submarines, surface ships, and underwater weapons equipped with acoustic pingers. These tracks are relayed in real time via satellite from the range operations center to the TCTS core, instrumentation where they are integrated with the track and event data collected from exercise participants via the TCTS datalink.

When submarines operate off-range in the open ocean, time-tagged underwater track and event data are, collected by the TCTS core instrumentation on a post-event basis via one of two methods:

(1) The submarine comes to communications depth and transmits data (e.g., via satellite relay channel)

(2) The submarine loads data into a SLOT-buoy-type device (e.g., AN/BRT-6 SATCOM buoy) and releases the device from operating depth. The device ascends to the surface and transmits data via the Submarine Satellite Information Exchange Subsystem (SSIXS) channel.

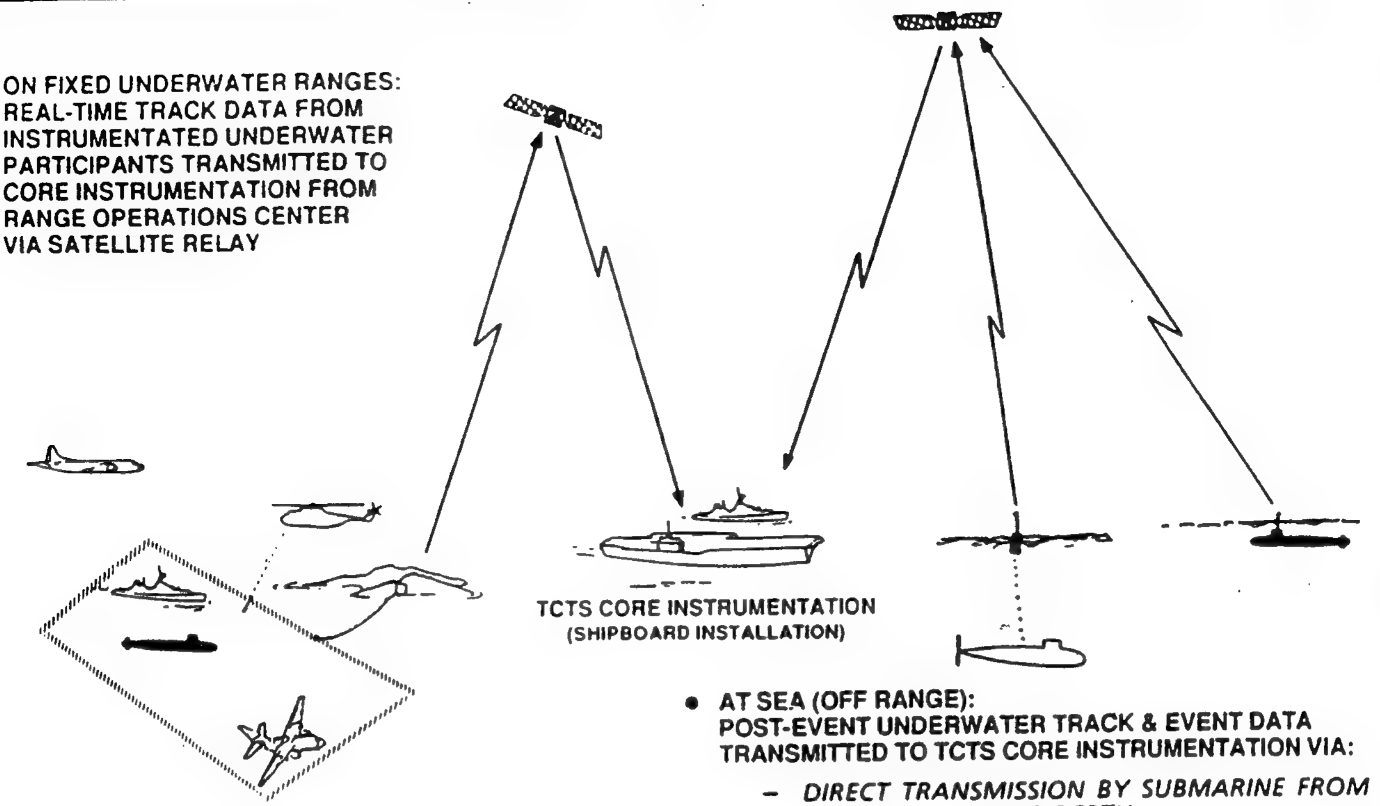
In either case, the satellite relay transmissions may be received directly by the TCTS core instrumentation or they may be relayed to the TCTS core instrumentation by the cognizant Submarine Operating Authority (SUBOPAUTH).

* Or portable underwater tracking ranges such as are under development by the Naval Undersea Systems Center (NUSC).

EXAMPLE TCTS BATTLE GROUP TRAINING SCENARIO

DATA RETRIEVAL FROM SUBMARINES

- ON FIXED UNDERWATER RANGES: REAL-TIME TRACK DATA FROM INSTRUMENTATED UNDERWATER PARTICIPANTS TRANSMITTED TO CORE INSTRUMENTATION FROM RANGE OPERATIONS CENTER VIA SATELLITE RELAY



- AT SEA (OFF RANGE): POST-EVENT UNDERWATER TRACK & EVENT DATA TRANSMITTED TO TCTS CORE INSTRUMENTATION VIA:
  - *DIRECT TRANSMISSION BY SUBMARINE FROM COMMUNICATIONS DEPTH*
  - *RELEASE OF SLOT-BUOY-TYPE DEVICE FROM SUBMARINE OPERATING DEPTH*

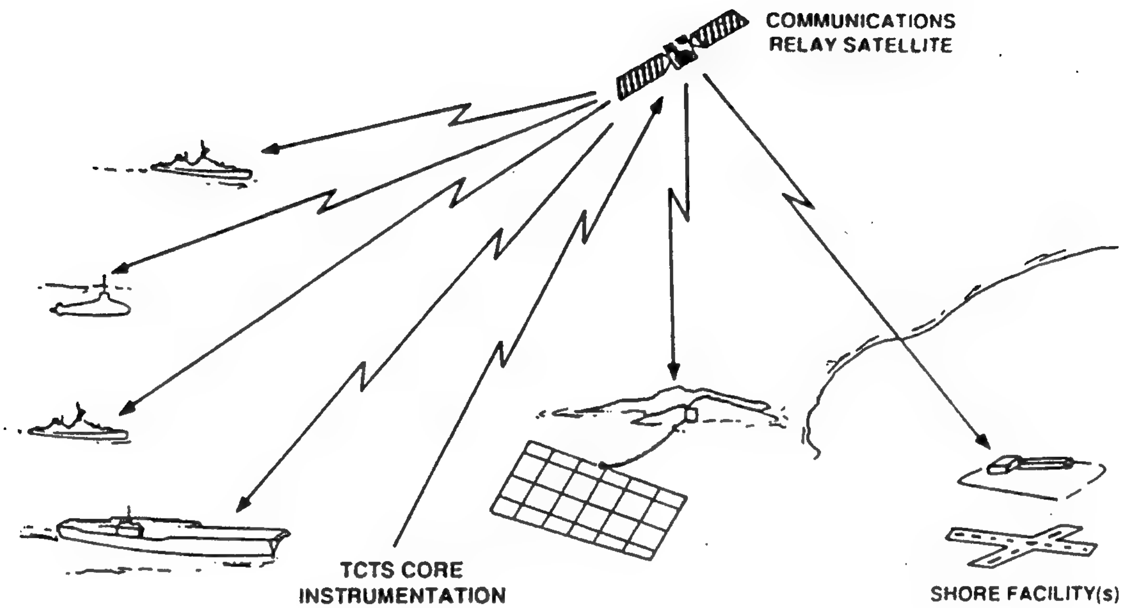
Debrief

Upon completion of the exercise, the training officer interacts with the core instrumentation to initiate the final correlation and integration of all exercise data collected by the TCTS. A consolidated mission history database is generated by the core instrumentation and transmitted via communications relay satellite to all of the locations afloat and ashore where participating personnel are located. This mission history database is then used at each location to provide exercise replay and debrief, either on portable TCTS display/debriefing stations or on available installed display systems via TCTS-provided interfaces. The exercise replay/debrief presentation can also be viewed at the TCTS core instrumentation monitoring/control station. Potential ashore recipients of the mission history database for this example Battle Group exercise include the home naval air station of participant VP aircraft, the range operations center at the underwater range, and the Submarine Operating Authority (SUBOPAUTH), which can relay debrief data to participant submarines via appropriate submarine force communications channels if direct reception of satellite-relayed TCTS debrief data by the submarines is precluded by their operating schedules.

EXAMPLE TCTS BATTLE GROUP TRAINING SCENARIO

DEBRIEF

- CORE INSTRUMENTATION PROVIDES CONSOLIDATED MISSION HISTORY LOG TO PARTICIPANTS & SHORE FACILITY(s) FOR REPLAY/DEBRIEF



TCTS CONCEPT OF OPERATIONS--SUMMARY

This short executive overview can be summarized by these three major points:

First--Tactical training capabilities for deployed forces must be improved, emphasizing all levels of training from individual platforms through battle group/force and collecting the data needed to support assessment, tactics development, and OT&E.

Second--The requirements for a TCTS emphasize greater realism in the combat training environment, accurate assessment of multiparticipant tactical training engagements, and comprehensive event monitoring along with timely interactive feedback for the individual units undergoing the training.

Third--Available technology can be used to meet the TCTS requirements and provide enhanced training capability to the Fleet.

TCTS CONCEPT OF OPERATIONS

SUMMARY

- NAVY NEEDS IMPROVED TACTICAL TRAINING CAPABILITY FOR DEPLOYED FORCES
  - *INDIVIDUAL PLATFORM THROUGH BATTLE GROUP/FORCE LEVEL*
  - *SUPPORT READINESS ASSESSMENT, TACTICS DEVELOPMENT, & OT&E*

- TCTS MUST PROVIDE:
  - *GREATER REALISM IN THE COMBAT TRAINING ENVIRONMENT*
  - *ACCURATE ASSESSMENT OF MULTIPARTICIPANT TACTICAL TRAINING ENGAGEMENTS*
  - *COMPREHENSIVE EVENT MONITORING & TIMELY INTERACTIVE FEEDBACK*

- AVAILABLE TECHNOLOGY CAN MEET THE REQUIREMENTS

"Embedded Training Capabilities for the LAMPS MK III System"

By
Robert S. Romalewski, NOARL
James Hammond, NOARL

" Embedded Training Capabilities for the LAMPS MK III System"

Robert S. Romalewski and James H. Hammond

Abstract:

An SH-60 helicopter incorporation the Light Airborn MultiPurpose System (LAMPS) MK III was tested using the AN/SRQ-4 UHF secure data link to an AN/SQQ-28 Sonobuoy Processor at the Naval Air Test Center (NATC) Patuxent River, MD. During the time the helicopter was on the simulated mission, it "dropped" sonobuoys and received normal mission feedback. This was done during testing of a potential wide-area network, with the acoustic stimulation for the LAMPS MK III accomplished by passing control and acoustic information from an AN/SQQ-89 On-Board Trainer (OBT) at Patuxent River via an on-site data link network. A master control unit was used to drive NATC's OBT from Fleet ASW Training Center, Norfolk, over normal telephone lines. Multiple OBT connections from the master control unit are possible and will further team training by combining expertise located at another training center with all other connected assets. Other additions to the OBT interface will provide additional aircrew radar training via the AN/APS-124 Remote Radar Operator (REMRO) system and EW software upgrades. The OBT is used at NATC in evaluation of helicopter ASW subsystems as well as for training.

Overview:

The LAMPS MK III aircrew currently benefits from an extensive embedded training capability using the AN/SQQ-89(V)-T() On-Board Trainer. This trainer provides both air and ship crew ASW training utilizing an actual SH-60 helicopter in the air or on deck as well as a simulated helicopter mode for training ship's crew. The aircrew can perform all functions necessary to prosecute a complete ASW problem including placing sonobuoys, operating with the Air Tactical Operator (ATACO), and using their Magnetic Anomaly Detector (MAD). Figure 1 shows the environmental and tactical system affected by the OBT and LAMPS MK III. The LAMPS MK III system is tied to the AN/SQQ-28 sonobuoy signal processing system,

via the data link. A complete LAMPS MK III sonobuoy inventory is available.

Recent R&D sponsored by the Surface Ship ASW Combat Systems Program Office will update the Electronic Warfare Simulation (EWSIM) program and add capability to train the AN/APS-124 Radar Operator and Remote Radar Operator on board ship. An upgrade from a single ship and single LAMPS MK III helicopter trainer to a Multi-Ship - Multi-Environment Networked Training and Operational Readiness system (MS-MENTOR) wherein multiple ships and aircraft are trained in a battle group configuration is currently underway.

Technical Parameters:
The OBT currently simulates EW targets for both the AN/SLQ-32 shipboard EW Receiver and the LAMPS MK III AN/ALQ-142 EW Receiver. The OBT also handles acoustics such as the AN/SQS-53 hull-mounted sonar, the AN/SQR-19 towed array, and AN/SQQ-28 LAMPS MK III sonobuoy processor, which are stimulated through an inverse beamformer. The main thrust of the new development are to extend the current operational system via MS-MENTOR, partially test MS-MENTOR as the scenario controller, and incorporate added features for the SH-60 helicopter crew. In the OBT, EW and ASW targets are generated in a gaming area of 2048 x 2048 nautical miles, to an altitude of 100,000 feet and to a depth of 5,000 feet. These targets are then position-kept in the OBT, and echo/emissions become visible to the sensor operators when the signal-to-noise ratio of these targets is such that it exceeds the detection threshold of the sensor systems. The ESM Contact Generation function of the OBT has the ESM processor manage and control the injection of ESM emitter parameters into the shipboard (AN/SLQ-32) and LAMPS MK III (AN/ALQ-142) sensors. Radars, communications emissions, data links, and weapon seekers are all provided in a geo-tailored ESM library of emitters. Helicopter position data is utilized for platform visibility and angle of arrival as part of the position information. The ESM processor continuously computes (at a 4 Hz rate) for update transmission to the sensors these last

two, plus signal propagation loss, ducting values, and parameter changes.

The LAMPS Tactical Data Simulation (TDS) processor in the OBT communicates, via a standard NTDS Type A (Slow) interface, with the AN/SQQ-28 Shipboard Processor Operation Program for the purpose of exchanging sonobuoy and LAMPS MK III status information. TDS also provides for Magnetic Anomaly Detector Simulation, ordnance management, sonobuoy management, and ESM message routing to the helicopter. Were the helicopter not available, the TDS would role-play in its stead. In normal operation, the LAMPS MK III ESM air subsystem is controlled from the AN/SLQ-32 by the ESM operator, and all ESM data is downlinked for analysis and display. The data link also provides transmission of tactical instructions, weapon delivery information, and other processed data (such as digitized voice communications) back to the helicopter. Feedback to the LAMPS helicopter allows for a variety of scenarios and crew training.

LAMPS MK III AN/APS-124 and Remote Radar Operator (REMRO) Training: The AN/APS-124 Radar Operator aboard the helicopter as well as the Remote Radar Operator aboard ship manning an OJ-194 console do not receive formal training. The LAMPS MK III Fleet Project Team identified this training deficiency four years ago, and it has since been validated by OPNAV letter with an OBT requirements change to add the requirement for OBT to provide embedded training for these functions.

There is an ongoing proof-of-concept to determine the validity of the approach to add this training feature. The proposed approach is to add an APS-124/REMRO simulation unit to be temporarily installed aboard the LAMPS MK III helicopter which would feed a simulated radar picture into the output of the APS-124. This block diagram is shown in figure 2. A trade-off study done by Raytheon of whether a radar simulator located on the ship with uplink radar video or a portable radar simulator that could be mounted in either

the helicopter or ship was done in FY 91. The study found the portable system the most cost effective solution. Figure 3 shows the location of the temporary unit on the helicopter. Initially, coordinated ASW/EW/radar target features would be provided, but not radar landmass. The proof-of-concept will be completed at the Ship Ground Station at NATC Patuxent River by Feb 92. Funding to implement this feature will be dependent on the budgetary process for FY92 and outyears.

The need for coordinated team radar training, coming from air team feedback, requires an upgrade to the OBT to provide a LAMPS MK III radar training capability and integrated acoustic and ESM training. Part of the proposed functionality is the operation of the AN/APS-124 LAMPS MK III airborne search radar to detect targets beyond own ship's capability, including low flying aircraft and anti-ship missiles. Other aspects include intercommunications with other MK III tactical team members and units; operator airborne IFF interrogation to challenge unidentified contacts; correlating EW information with MK III tracks; entering target data generated for display and analysis, and updating all displays.

Electronic Warfare Simulation (EWSIM) Upgrades:
There is a special program that is part of the LAMP MK III Airborne Operational Program (AOP) called EWSIM that is loaded for the EW training mode in the helicopter. This program is currently being upgraded by the Naval Air Development Center (NADC) to add helicopter threat warning capability and to make other software improvements. This program upgrade will be tested in Feb 92, and will probably be made part of AOP fleet release 20 or 21.

OBT ASW Training Capabilities Applied to Non-LAMPS Platforms:
Directional Frequency Analysis and Recording (DIFAR) scenarios require no interface between the trainer and the receiving platform. In the currently prototyped "School House" mode, OBT generated DIFAR scenarios can be used by non-LAMPS ASW platforms. Active scenarios, however, require that the OBT receive returned

"trigger" signals to denote initiation of active sonar pings by the airborne platform. NATC engineers have conceptualized a modification which would provide a means of receiving Directional Command Activated Sonobuoy (DICAS) ping trigger signals from non-LAMPS aircraft. This modification would improve the OBT's utility by providing both passive and active acoustic training support for the P-3, S-3 fixed wing, and the SH-2F, SH-2G, SH-3H, SH-60F or non-LAMPS MK III helicopter communities. If fleet interest is found to exist, funding will be sought for development of a prototype ping trigger receiver/decoder. This modification would broaden the applicability of the AN/SQQ-89 trainer, and would further enhance its usefulness for support of integrated battle force ASW training.

Non-Training Applications of the AN/SQQ-89/OBT:
Engineers at the Naval Air Test Center, Patuxent River, MD are making use of the AN/SQQ-89 On Board Trainer in areas outside the training arena. As an example, OBT Directional Frequency Analysis and Recording acoustic scenarios were transferred to tape. These scenarios were then used to support Navy evaluation of the SH-2G helicopter integrated ASW mission system. The OBT was also used to provide ASW scenarios for the SH-60B helicopter system software developmental test and evaluation. Additionally, the OBT provides acoustic stimulation during SH-2F, SH-2G and SH-60F helicopter ASW test and evaluation as well as the SH-60B.

Planning is underway to develop procedures that will permit deployed LAMPS MK III system maintenance personnel to verify integrated ship/air acoustic processing performance using the OBT as an acoustic signal source. This application will provide both ships company and embarked aircraft maintenance personnel with a means of evaluating sonobuoy receiver, acoustic processor, and display performance using signal levels which approach the detection threshold.

MS-MENTOR:

The Fleet ASW Training Center Atlantic in Norfolk, Virginia, is the evaluation testbed for the Multi-Ship - Multi-Environment Networked Training and Operational Readiness system: a Raytheon IR/IRED initiative, which controls multiple AN/SQQ-89 On-Board Trainers for ASW work. This control is set up via a network construct termed OBT-NET, and supports the Battle Force Tactical Training (BFTT) program. The Ship Ground Station at the Naval Air Test Center serves as a link to the OBT and LAMPS MK III. Battle Force Tactical Training units in the Chesapeake Bay - Norfolk area are another potential network linkage. A mobile trailer configuration for the host node which allows the MS-MENTOR configuration to be transported to other ports of opportunity has been developed by the Naval Oceanographic and Atmospheric Research Laboratory (NOARL).

The main thrust of our new development was to extend the current operational system by adding multi-ship networking, and partially test MS-MENTOR as the scenario controller. Evaluation of the last component, MS-MENTOR, is ongoing under the auspices of the Naval Underwater Systems Center (NUSC). Multiple OBT connections from this master control unit are possible and will further team training and asset coordination. Even if only utilized on a limited basis, it can provide training for crew and linked ASW team members, combined with expertise located at another training center. In this specific case, a LAMPS MK III helicopter at NATC was connected through the AN/SRQ-4 UHF data link to the OBT at NATC, and the MS-MENTOR system in Norfolk. Monitoring of the exercise, and by extension any multiple air-sea platform grouping, was done at the scenario's central control in Norfolk, as well as at NATC. The MS-MENTOR system can currently provide external control of up to eight OBT's, and can itself be slaved to an external controller through BFTT. Figure 4 shows a schematic of the MS-MENTOR test configuration to the other players.

The external control for the scenario could be another higher level training system, such as the AEGIS Combat Training System (ACTS),

which in turn would incorporate Anti-Surface Warfare (ASUW) to the Anti-Air Warfare (AAW) and Anti-Submarine Warfare (ASW). The airborne ESM system of the LAMPS MK III can be viewed as an extension of the shipboard EW system. The advantage of the MS-MENTOR unit lies in its capability to tie several OBT's and their associated network components together. A NTDS Link 11 implementation using ACTS to other OBT's would be limited to only ships having the AEGIS Combat Weapons System, whereas the MS-MENTOR approach would allow all AN/SQQ-89 ships having an OBT to participate. The OBT will contain an interface to ACTS with the release of AEGIS Baseline 4, and has an external control port for stimulation control from sources such as the 20B5 FFG7 Pierside Team Trainer. The existence of an external control port and an associated software design that allows for OBT control from an outside source will allow BFTT to interface with the OBT with no modifications required to the existing OBT.

In order to pass information within the MS-MENTOR structure and among the dissimilar components, network interoperability is required. An open system computer network architecture, which is supported by the services and industry, that uses standard protocols is nearing its' final draft form in the Distributed Interactive Simulation (DIS) protocols, and will be released as an IEEE standard. It supports the simulation devices being present in one location, interconnected by a Local Area Network (LAN), or widely distributed on a Wide Area Network (WAN). As the simulation network is expanded, each new player or functional unit brings with it all of the computational resources necessary to support itself. This fits into BFTT and the MS-MENTOR configuration.

Summary:

We have talked about the embedded training capabilities of the LAMPS MK III and OBT systems. The OBT is used for more than just training at NATC, and has not reached the end of its usefulness yet. Within the BFTT arena, initial tests of the MS-MENTOR were successful, and it was shown that resources throughout a wide area

can operate together for team training. Future additions to Navy resources will be the DIS tri-service computer interoperability protocols, EW upgrades, and REMRO capabilities.

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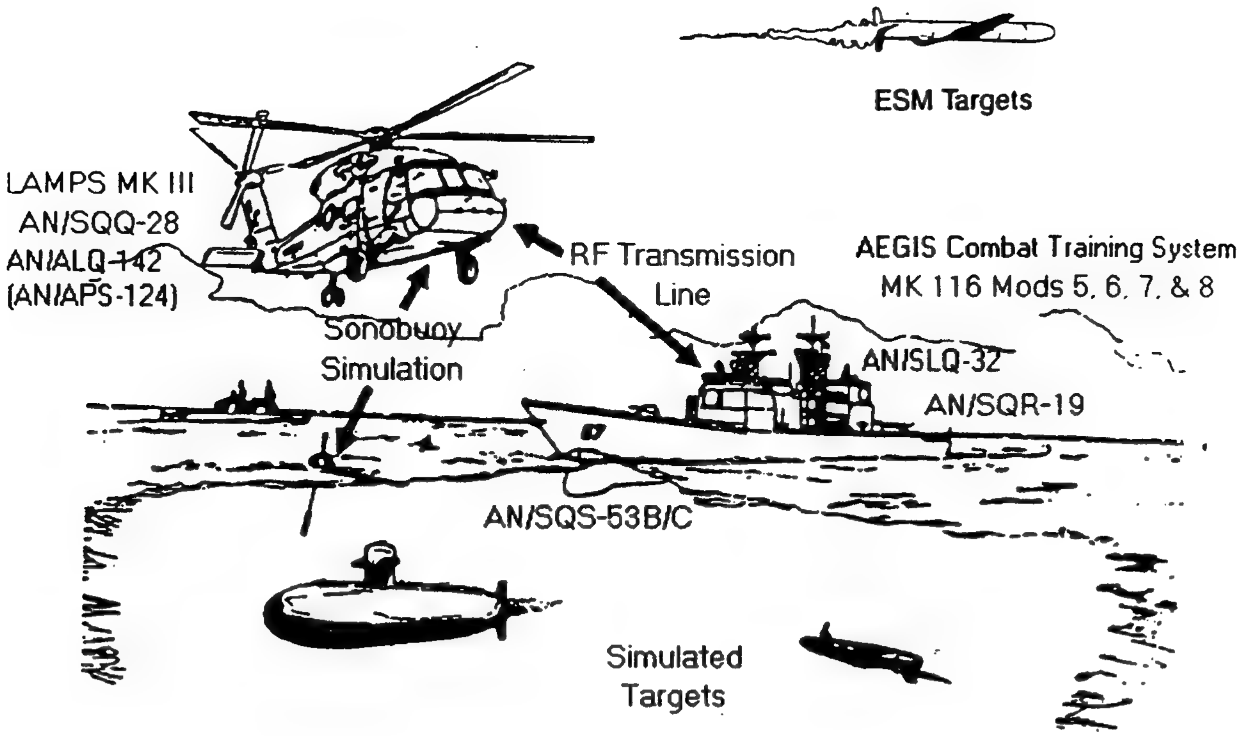


Figure 1. OBT Environment.

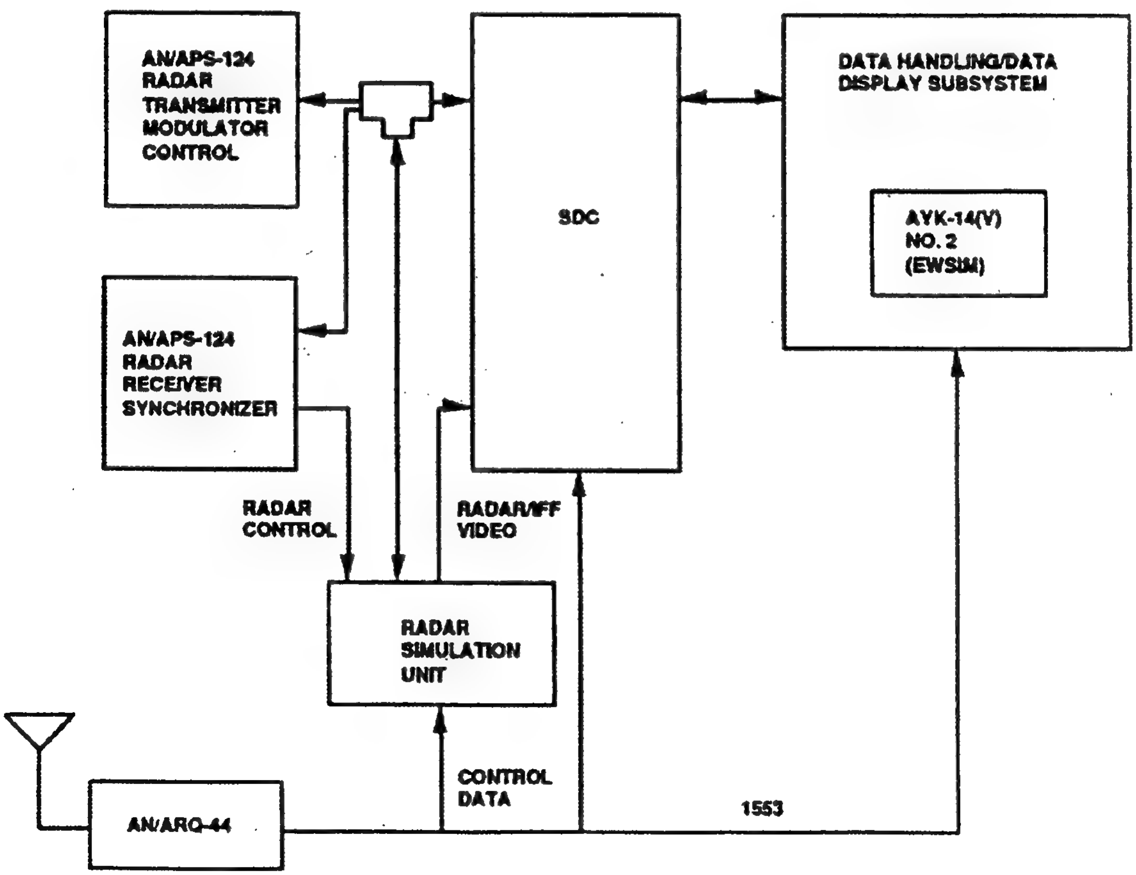
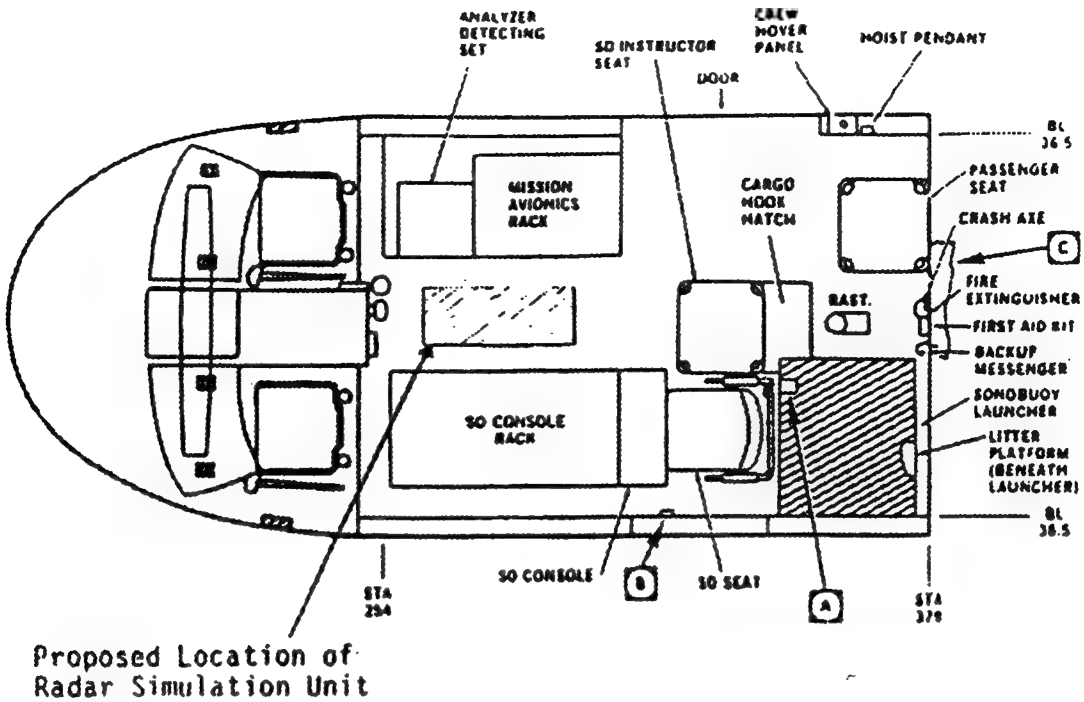


Figure 2. Radar Simulation Unit Connection Diagram (Air Team Training Configuration).



AIRCRAFT LAYOUT

Figure 3. SH-60 Internal View.

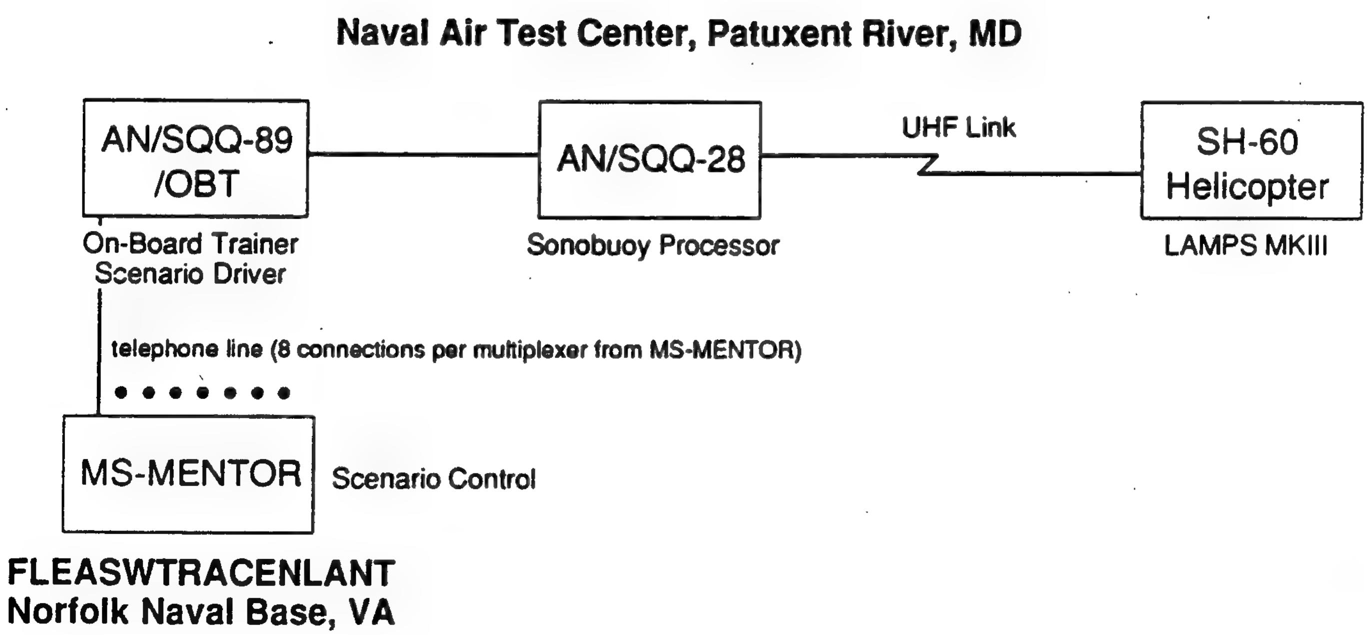


Figure 4. OBT-NET and MS-MENTOR Connectivity.

PROBLEMS AND SOLUTIONS IN LARGE-SCALE COURSEWARE DEVELOPMENT

by

Patricia Hickman

Third Annual Airborne Weapons Technology Review and Training Exposition
San Diego, California
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The problems of developing Computer-Based Training (CBT) and training in general get more difficult as we push on to the 21st century. The tasks that we are being asked to develop training for are becoming more technical and sophisticated while our audience and our developers become relatively less capable. In an Executive Summary published in 1987 by the Hudson Institute entitled *Workforce 2000, Work and Workers for the Twenty-First Century* they list six challenges facing American jobs and workers between now and the year 2000. These six issues are:

1. Stimulating Balanced World Growth
2. Accelerating Productivity Increases in Service Industries
3. Maintaining the Dynamism of an Aging Workforce
4. Reconciling the Conflicting Needs of Women, Work and Families
5. Integrating Black and Hispanic Workers Fully Into the Economy
6. Improving the Education and Skills of All Workers

All of these challenges effect us in one way or another but the one that we can have a more direct impact on is the last one, Improving the Education and Skills of All Workers. Clearly this challenge needs to be met while tomorrow's workers are in today's schools. However, this may or may not happen and we will be forced to meet this challenge in the workplace, regardless. As the need for higher skilled employees increases we will have to be more creative in the development of our training as well as in the tools that we use to develop that training. As the gap between the existing skills and abilities of employees versus the requirements of advanced technology widens our challenge will be ever greater. As systems get more technologically sophisticated we will have to train our employees to utilize and maintain those systems. The skills of these employees will have to be learned on the job in many cases, through the training that we provide.

As trainers, we will have to become more sophisticated in the development of our training and the use of the training tools available to us. Training technology continues to advance. Computer-based training has been around for many years but is only now starting to reach a wider audience and acceptance. We must continue to break ground in our use of the newer training technologies.

This means that we have to use more advanced tools in the development of our courseware. As CBT is accepted and utilized the call for more CBT will increase. In developing all this interactive, mediated instruction we are faced with many problems. I have noted one problem, the less skilled worker and developer. With more courseware being developed comes the problems of not only developing large amounts of courseware but also maintaining that courseware. How do you manage such tasks? How can you streamline the standardization of a courseware project? How can you take advantage of the technology to better organize the project? How can you make your development staff more productive? Are there tools available to help with these problems? I believe that there are.

One of the most significant advances in training development technology in recent years is called "lesson generation." The philosophy behind lesson generation is to take as many decisions as possible concerning a course and capture those in project-wide software models. Some of those decisions include use of graphics and color, learner control, instructional design, and audio and video. Capturing more and more of these definitions on a project-wide basis you cut down on the number of subjective decisions on all these dimensions to be made by individual developers. This has the effect of increasing consistency, policy, instructional rigor and overall quality while at the same time it greatly improves productivity and maintainability.

The interactivity and instructional sophistication of a course can be approximated by the level of branching complexity. Learner control is very important to the student's ability to explore and make the most of the training experience. The greater the learner control the more accommodating this is to varying learner styles and abilities. Having greater learner control allows one course to cover a wider range of needs. Many lessons have been considered complex if they allowed 4-6 branches per frame. In large measure, learner control has been dictated by the flexibility of the tool being used to develop the courseware. Traditional authoring systems usually require that all branches be made by hand and then debugged and tested in the same manner. This makes a rich learner control environment very expensive. Using lesson generation you can define all of the learner control globally for the project. The branching can then be debugged and tested one time. In a course developed using lesson generation for SAS for Boeing 767 aircraft, the level of branching complexity from any given frame varied from 20-28 choices. This allowed the students a great deal of freedom and made their training more effective. Overall, lesson generation gives you greater productivity and consistency and you can aspire to more learner control than traditional methods without increasing the development cost.

For example, when the project staff decides on the location of screen icons for learner control you can capture that one time in the "course level" software so no developer will ever have to specify these for any screen of any lesson. These will then be supplied automatically in all lessons. Therefore, you cut down on the amount of time for debugging and testing of courseware. In the future if you want to change the look or location of the icons (or, perhaps, more fundamentally, the "behavior" of the course) it is a simple matter to change it in one or two places and those changes can be reflected in a matter of moments throughout the entire course. You would not have to debug or test the course to make those global changes. This helps cut down the costs of CBT development significantly.

This also helps the student because they can always depend on certain things being in the same place and behaving the same way every time. How many times have you worked with a new piece of courseware and wondered how to exit this program or make something happen that was similar in another program, but is slightly different in this one? You have to continually relearn and assimilate those differences. By making global decisions you cut down on that learning process leaving more time and energy available for the real training task.

Lesson generation also allows the different development tasks to go on simultaneously, such as graphics development, logic development, and video and audio development. This increases the overall productivity. Because one product is used for the entire development process, communication between the designers, developers and subject-matter experts (SME's) is increased. Figure 1 shows how the separation of content and instructional strategy with lesson generation may be used.

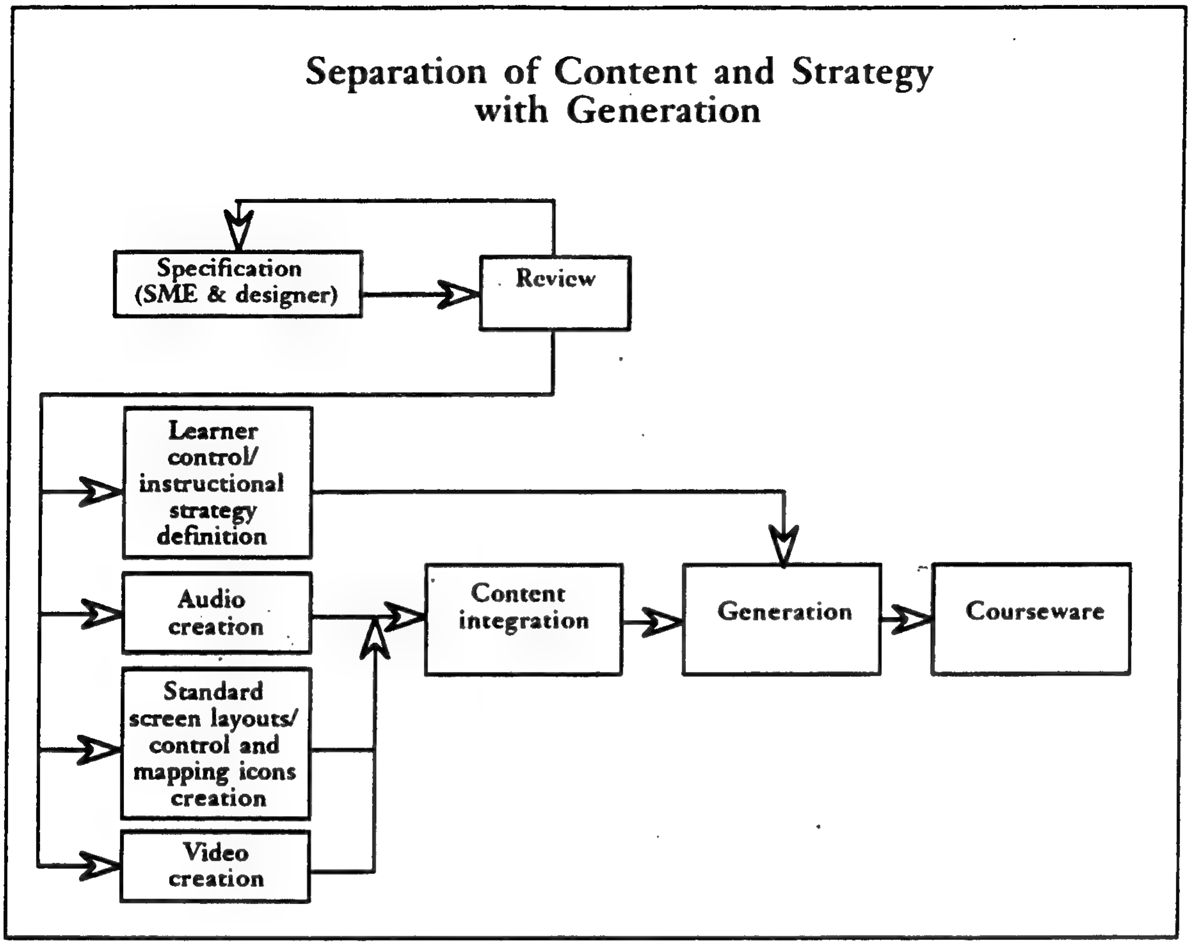

Figure 1

As computer technology continues to get more sophisticated the user-interface has gotten easier. This helps with the problem of the lower-skilled developer. No longer do we require a computer programmer to develop our CBT, thanks to authoring systems, and even they have become more user-friendly through the use of highly graphical, icon-oriented systems. We can now import highly realistic scanned images and use a combination of still and motion video to help in our training so we require less skill in graphics development. Through the use of data bases and electronic communications organizing and managing a large project can be much easier.

One of the most difficult tasks at the beginning of any large-scale courseware development project comes in the establishment of standards for instruction , graphics, use of media such as audio/video and general organization. It is absolutely vital to a students success that these problems be ironed out. Otherwise, the student is constantly battling the courseware and learning in spite of it, not because of it.

Early in the development of the project a critical issue is the standardization of instruction. One area that has lagged behind in the development of authoring systems and tools is in the incorporation of quality instructional design. The focus has been on the computer and the interface. We have relied on in-house instructional design expertise, if we had it at all, to solve the instructional problems. Having the appropriate talent on hand for a large-scale project can be very expensive, by the time you have all the project development staff, subject-matter experts, etc. Quite often the instructional development is left to the SME who may not be qualified to make instructional decisions. If you have instructional designers on staff they are usually not all going to produce courseware at the same level of quality or ability. Very often the instructional design in your course becomes a product of the lowest common denominator or ability of the least-skilled designer. To ensure instructional rigor requires a large staff of people to manage and review all of the work done by these instructional designers, thereby increasing the costs while not guaranteeing the quality.

A system that could take advantage of available in-house instructional expertise as well as incorporate the knowledge of the country's leading experts could prove invaluable to a project. One such system that does this is called Sage. Sage allows you to capture the expertise of your best designers concerning instructional strategies, learner control functions, standard screen layouts and control and mapping icons. This expertise can then be incorporated into instructional templates that will be used by all. On-line advice on project standards, instructional problems, etc. is incorporated into the template so all developers can work to the highest-skill level rather than the lowest.

Each project should begin with the assembling of a project design and standards team. At this time you should establish as many of the project ideas and standards as you can. By getting everyone together you have a consensus that everyone buys into, helping to alleviate future problems of style or instructional difference. This does not eliminate problems, but it will help cut down on them significantly. Once you have a consensus on the instructional standards, the templates and advice can be developed or modified.

This is also a good time to begin establishing graphics standards and media decisions. The media decisions are not whether or not to use video or audio, this should have been decided in a media analysis prior to this point. However, how much and where to use video/audio can be ironed out. It is important to keep in mind the relative costs of different media. Is it cheaper to use a large amount of still video images, have a graphics artist draw them, or scan photographs of the images using a color scanner? These costs are all known and are obviously a deciding factor, but the instructional validity of a given media has to be considered as well.

It is also important to consider the "edutainment" value for the student. In today's sophisticated society, student's are no longer impressed by simple computer graphics. They are used to seeing very advanced computer graphics and video "tricks" on television and at the movies. This is not to say that the expense of these items gives you a one-to-one increase in training effectiveness. However, we would all agree that given the choice of seeing the same training materials in black and white or in color we would usually opt for the color presentation, simply for the increased visual appeal. There is a tightrope that must be walked when making these decisions. The use of 256 colors vs. 16 colors may result in more appealing graphics with greater shading options, etc. but the cost of such graphics may be so high that you should standardize on a 16 color palette for the majority of the courseware, leaving 256 colors for those graphics where it is essential. Today's technology allows you to make such decisions. You can also mix still and motion video, computer-generated as well as digitally stored audio. Through the use of DVI technology you can store all of your audio and video information on a hard disk or CD-ROM and eliminate the use of a videodisc player.

Once you have established your instructional, graphics and media standards you can design the management and organization of the project. The cost of initial development often contributes less than 40% of the life-cycle cost of a piece of courseware. In other words, when you have paid for the initial development of courseware, you haven't even spent half of what you will before you throw it away. This makes meaningful organization and management even more vital.

It is essential to formalize the communications between each step of the task and how data will be gathered and stored. Technology now allows text and graphics to be referenced in multiple lessons but stored in one place. This aids greatly in the development and maintenance tasks. You can store one image of a given graphic and use it in hundreds of lessons. When that graphic image changes you need only change it in one place to have it affect all lessons. The same is true for text. Figure 2 shows an example of an aviation project that incorporated the use of referenced graphics into the lesson generation process.

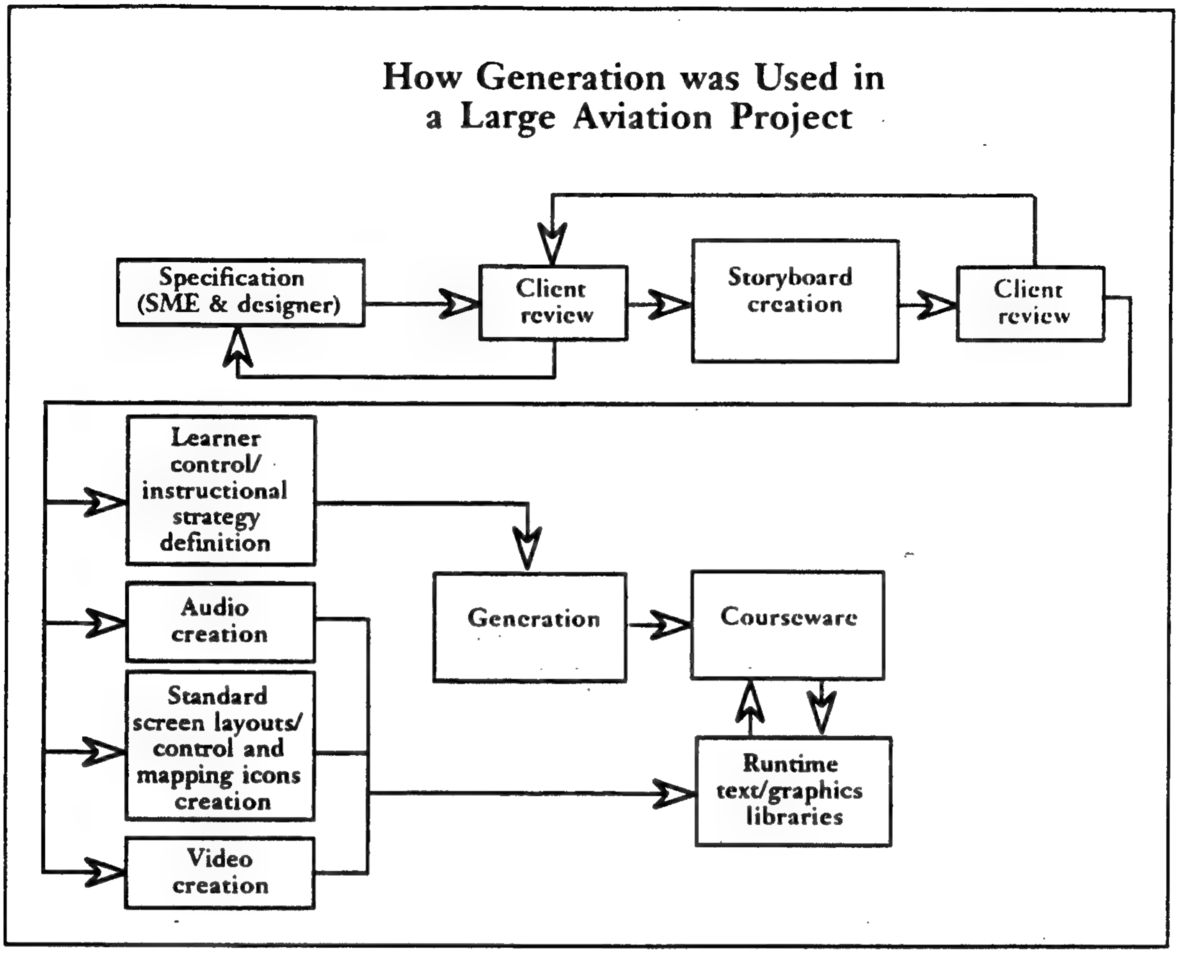

Figure 2

With this technology comes an added responsibility for organization and management. One tool that could be invaluable in storing all this data is an on-line database. All text and graphics and their related files can be managed in the database, available for all developers to retrieve information at any time. This data base could store not only the information about a given graphic but could also be a dynamic list of all lessons that might be affected by future changes. This will also increase overall productivity over the life of the courseware.

Technology will continue to move forward. It is a good idea to not get bogged down in the latest and greatest trends to come along. They don't always stick around. At the same time, it is a good idea to move forward with the technology. Computer vendors are becoming more aware of the need for flexibility between products and standardization of capability. How many of us own beta VCR's instead of VHS? By careful analysis you can keep abreast of the changes and take advantage of them without making costly mistakes. The courseware development task will become increasingly integrated in all facets.

Through the use of instructional templates it is possible to do all initial storyboard development on-line, no longer relying on a paper-based world. When you develop courseware using a system such as Sage you can try out your ideas at a much earlier point in the process, without wasting valuable time and money. The designer also has the opportunity to incorporate graphics, text, video and audio that have been under development simultaneously at a much earlier point. This makes the task of reviewing and revision much simpler and cheaper, because it can happen earlier in the development cycle. Having one, integrated tool helps significantly with the process. Working with a large development staff may require that lessons pass from one developer to another before completion. Having integrated development tools allows information to be included directly in the file as it is being developed, lessening the chance for mistakes to be made. If you have a smaller development task where more of the work is done by one individual integrated tools are just as valuable. If you are developing a prototype and are relying on the SME to develop the bulk of the effort, having on-line instructional advice, easy graphics storage and retrieval and simple audio/video development and incorporation allows him/her to develop a more complete prototype without having to rely so heavily on the expertise of others. The expertise is in the tools.

This is the wave of the future. It has to be. As our workforce becomes less skilled relative to the demands of the workplace and our pool of talent shrinks we will have to rely more and more on the technology and tools that are being developed. As trainers we will have to become more adept at our use and knowledge of the tools and technology that are available and as they are developed. We can't sit still because technology certainly doesn't. In order to meet the challenges of the future, we must think and work smarter than we have before and take full advantage of the technology.

SH-60F/CV-Helo OPERATOR AND MAINTENANCE TRAINERS

"BOUGHT FROM THE PRIME"

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Washington, DC

ABSTRACT

During the past several years, the benefits and risks of buying trainers/training from the aircraft prime have been discussed. This paper provides a history of the operator and maintenance trainers procured through the prime, Sikorsky Aircraft, for the SH-60F CV ASW Inner Zone Weapon System. The benefits and lessons learned from this successful "Buy from the Prime" procurement are also described in this paper.

1 INTRODUCTION

Igor Sikorsky recognized the complexity of operating a helicopter. He built his first flight simulator in the 1930's as a development and training device for his new flying machine, the VS-300. He used the simulator to study attitude control of the main rotor system, arrangements of mechanical control interfaces, and control gearing requirements. Using the simulator, he analyzed several configurations of flight controls, including tail mounted rotors for pitch and roll control. Piloting techniques were developed on the simulator before flight, as shown in Figure 1. His survival through this early period of helicopter development testifies to the value of training the pilot in a simulator before flight.

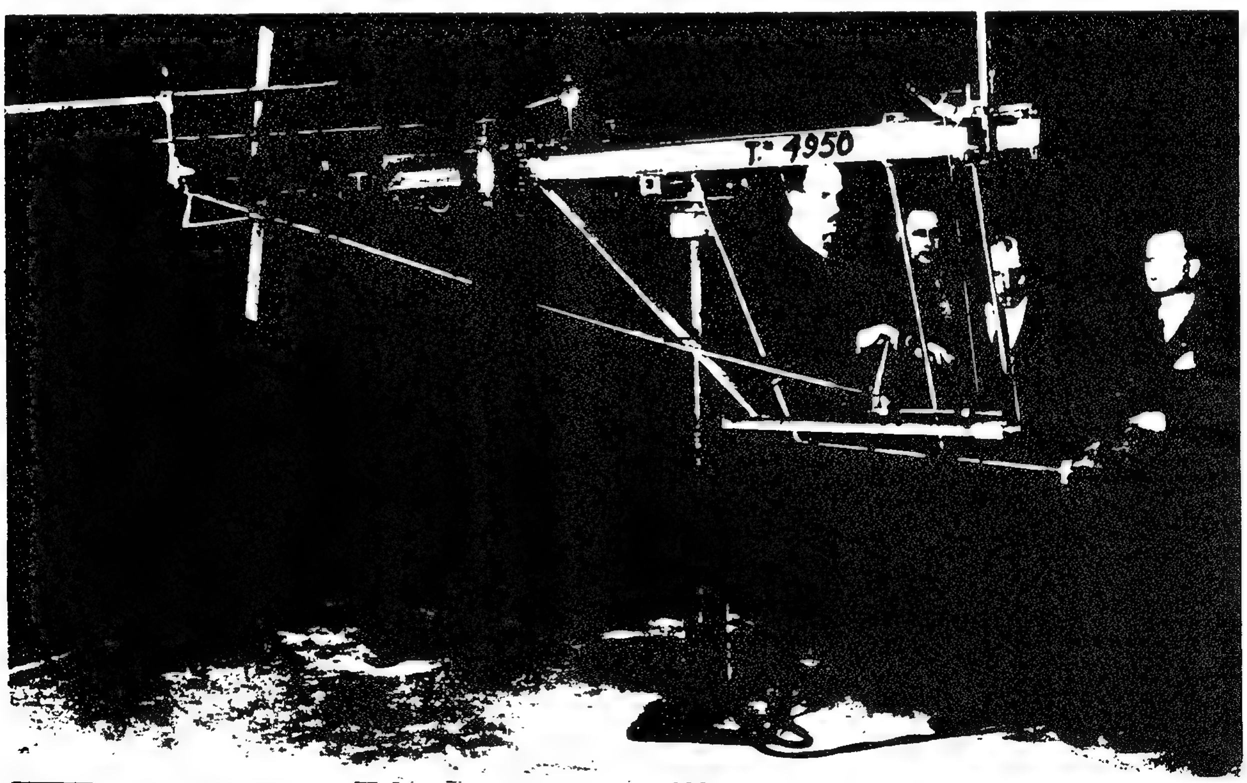

Figure 1 Igor Sikorsky "Flying" his first simulator, circa 1939

2 BACKGROUND - THE SH-60F AIRCRAFT WEAPONS SYSTEM

Under the Layered Defense concept, with inner, middle and outer zones, the Navy uses the SH-60B, S-3, and P-3 in the acoustically more dormant waters beyond the inner zone, approximately 30 miles from the carrier battle group. In the raucous inner area, where friendly ships are constantly moving, passive sonobuoys and towed arrays are less effective. The dipping sonar becomes the preferred ASW sensor. Besides the high ambient noise, being close to the battle group means that time lines compress. Minimal time is available to detect, track, and release a weapon against a threatening submarine. The SH-60F was selected to replace the SH-3H to patrol the inner zone. The SH-3H, produced in the 1960's, was fully depreciated and scarce when the Navy made the decision to upgrade to the SH-60F.

The very successful SH-60B SEAHAWK design was modified into the SH-60F for operation off the carrier, at the center of the inner zone. The SH-60F integrates the AN/ASN-150 Tactical Data/Communication System with the AQS-13F Dipping Sonar, sonobuoys and MK-46/MK-50 torpedoes.

Two pilots, an Acoustic Sensor Operator (ASO), and a Tactical Sensor Operator (TSO) operate the mission systems. A dual redundant MIL-STD-1553B data bus interfaces the sensor, armament, control and display subsystems. The CV-Helo is required to fly a unique mission in an extremely demanding operational environment. Often at night, the CV-Helo drops sonobuoys to listen passively for an aggressor sub, and then uses active sonobuoy and dipping sonar to track and target the threat. This routinely requires hovering at 50 feet at night over a hostile sea, dipping and retrieving up to 1500 feet of sonar sensor cable, dashing to the next dip point and repeating the process. This rigorous mission requires highly trained flight and maintenance crews to be successful.

Full scale development of the aircraft began in February 1985 and Navy operational evaluation (OPEVAL) was concluded in February 1988. Production aircraft delivery began in May 1989. The Navy plans to procure approximately 175 aircraft. To support the training requirements of this new weapons system, the Navy selected Sikorsky to provide trainer and initial cadre training.

3 DESCRIPTION OF TRAINING DEVICES

The Navy built two new facilities to house the SH-60F trainers, classrooms, and support activities. These facilities are located at NAS North Island, California and NAS Jacksonville, Florida. Sikorsky provided basic facility space, power, and environment requirements to the Navy within 60 days of contract award. The Navy designed and fabricated the first facility (NAS NI) in less than three years after receiving the initial facility requirements document.

3.1 Maintenance Trainers (MT)

Sikorsky designed and built Maintenance Trainers to support teaching the critical testing, trouble shooting and remove/replace skills required by organizational ("O" Level) mechanics. NAVAIR recommends the use of Aircraft Common Equipments (ACE). Wiring harnesses, black boxes and major assemblies (such as gear boxes and rotor heads) are aircraft common, where possible. This approach (using aircraft common rather than trainer peculiar equipment) provides the following benefits:

> Configuration identity, touch, weight, and feel of components are the same as on the aircraft.
>
> Non-recurring engineering effort to design simulated components is reduced.
>
> Spare parts are available from aircraft common Navy inventory.
>
> Maintenance tasks, logistics data, and post-overhaul testing for the ACE are the same for aircraft common trainer components.
>
> Engineering changes to aircraft are more readily incorporated into the trainer.

The advantage in using trainer peculiar equipment is that malfunctions and trainer unique requirements are more easily designed into the system. Using aircraft common equipment limits malfunctions to being inserted by outside-box stimulus or software.

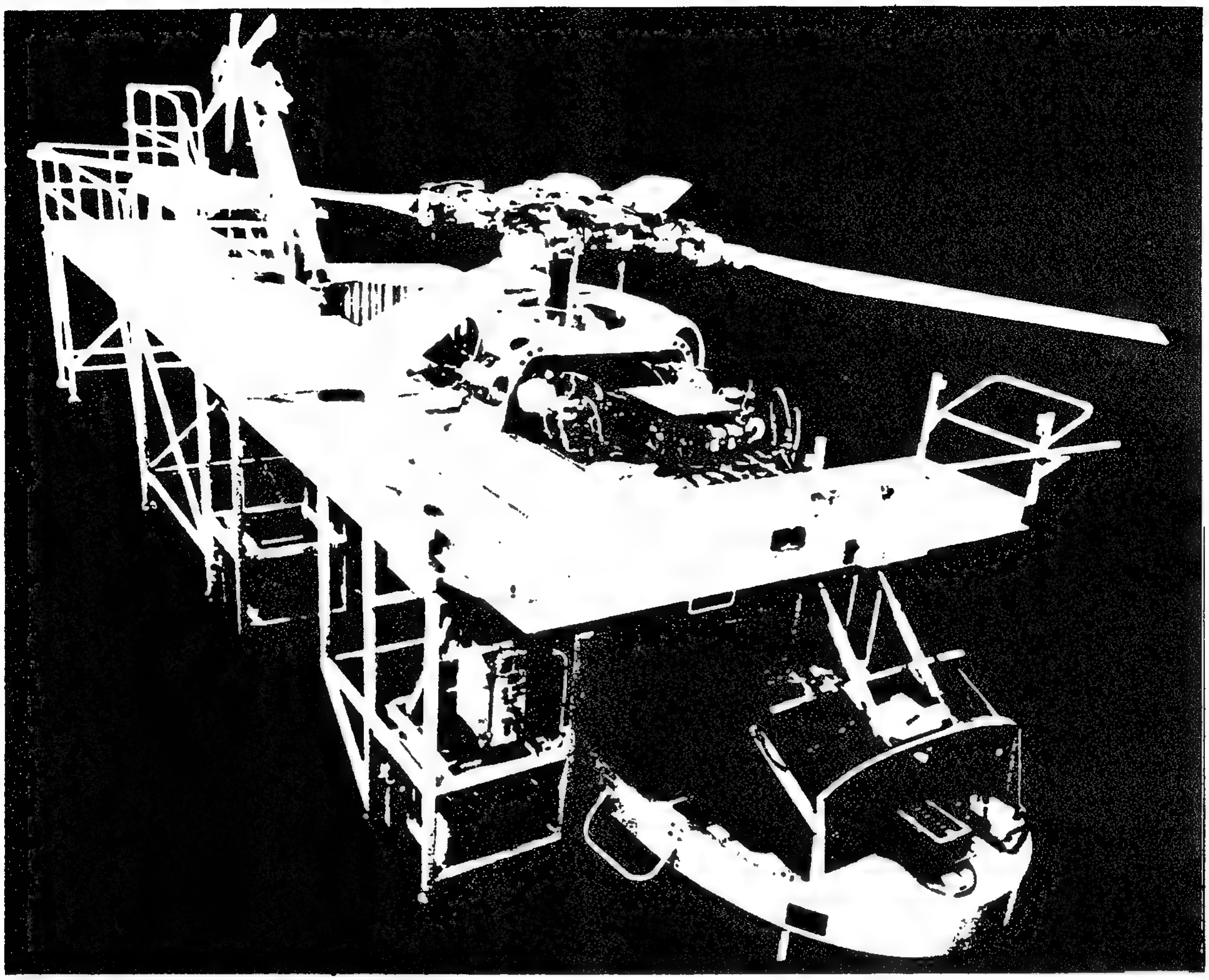

Figure 2 Composite Maintenance Trainer

The Maintenance Trainers' design concepts were based on the SH–60B Maintenance Trainers, which were delivered to Mayport and North Island in the late 1980s.

The Navy facilities at NAS North Island and NAS Jacksonville have the SH–60F Maintenance Trainers listed in Table I.

3.2 OPERATOR TRAINERS

The design concepts for the Operator Trainers were developed by the Navy and defined by the Navy's Design Specifications. These specifications were the basis for a formal competitive bidding process run by Sikorsky. The successful bidders were Norden Systems Company for the Weapon System Trainer (WST) and Acoustic Trainer (AT), and Teledyne Systems Company for the Tactical Team Trainer. Reflectone, Inc. was the principal subcontractor to Norden and provided the motion base, aero model, instructor stations, and some systems integration effort. Norden provided the Acoustic Trainers, Sensor Operator Trainers, underwater acoustic simulation, and Tactical Interface Unit. The Operator Trainers are listed in Table II.

The Operator Trainer design criteria included the following:

New designs - per Mil-Specification (for hardware and software)

Commercial equipment - permitted where economically appropriate (example: Visual System)

Table I Maintenance Trainers

Maintenance Trainer (MT)	Major Components/Description
Composite MT (see Figure 2)	Engine Transmission System Main and Tail rotors Hydraulic pumps and system Flight controls Active systems include: Blade fold & Pylon fold Automatic Flight Control Servo controls, etc. Vertical Indicator Display System Rotor Brake Fire Extinguishing Oil Warning Rigging Procedures
Avionics MT (see Figure 5)	Tactical Data System Navigation system Communication system Sonar System Sonobuoy Launch Above systems are active, as typically seen by a maintainer with power on the aircraft. Pilot, copilot, TSO/ASO stations
Landing Gear MT (see Figure 5)	Main Landing Gear Wheel Brake Floatation System
AFCS (Automatic Flight Control System) MT (see Figure 5)	AFCS Computer Vertical Gyro Indicating System Attitude & Heading Reference System Air Data System Stabilator
RAST/Tail Wheel/Hoist MT	RAST Tail Wheel Hoist
Main Blade/BIM	Main Blade BIM
Computer Controlled Panel MT (see Figure 5)	Hydraulic/Pneumatic Electrical Fuel
Ordnance MT	Armament System Bomb Rack Simulated torpedo

Acoustic data - Navy's Common Acoustic Data Base (CADB) and ocean data were used as source data for underwater targets in their environment.

Aircraft common equipment - when used, are flight qualified and interchangeable with the aircraft.

Note: Sikorsky modified the aircraft common Automatic Flight Control Computer to allow its use in either an aircraft or in a trainer (where problem freeze is required).

Government Furnished Equipment (GFE) - none.

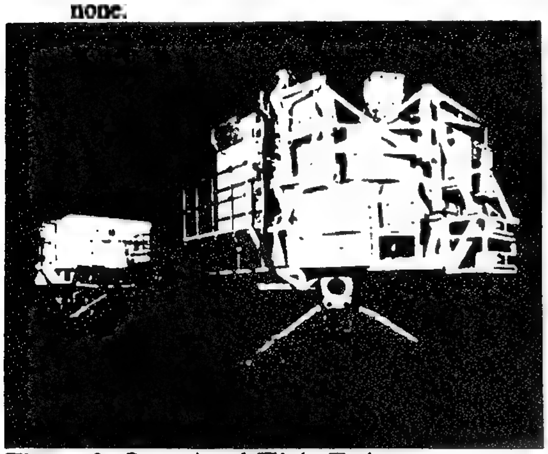

Figure 3 Operational Flight Trainers

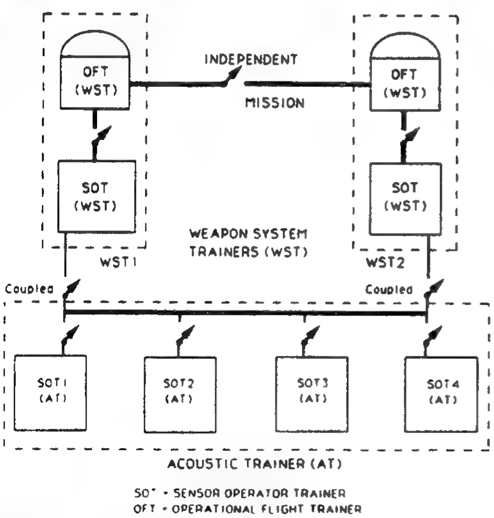

Figure 4 Coupled Modes and Mission Modes

4 INTEGRATED LOGISTICS and RELIABILITY

The Navy has a support contract with Loral for on-site maintenance of the Maintenance and Operator Trainers to ensure that they are fully operational. NAVAIR procured a "seed" set of spare parts from a variety of sources to support the trainers. Loral is required to repair or replace any equipment as necessary. The reliability experience at NAS NI has been very good. During the past year, the trainers have been available for scheduled training more than 95% of the time.

5 TRAINING OF INSTRUCTOR CADRE

Sikorsky provided a Pilot Familiarization course that described the differences between SH-60B and SH-60F aircraft. This course was given to SH-60B qualified pilots, who became instructor pilots at HS-10. Sikorsky, Norden and Reflectone presented instructor utilization courses to pilots and sensor operators. These courses provided detailed instruction on how to operate the trainers.

6 "BOUGHT FROM THE PRIME" ADVANTAGES

There are several benefits to the customer in purchasing Trainers and Training from the aircraft prime. These advantages are most viable when the trainers support a new model aircraft or a significant Engineering Change Proposal (ECP), which are being developed by the prime. These advantages are described below:

6.1 Single Point of Contact or "One call does it all."

A single point of contact saves cost and schedule to the customer for essentially all the routine and abnormal problems and tasks associated with any major trainer procurement. The customer has one discussion point for the innumerable issues and decisions required. With a multiple set of suppliers and data sources, the customer's effort to communicate and coordinate issues and answers would be significant.

Table II Operator Trainers

Operator Trainers (OT)	Description
Weapon System Trainer (WST), includes:	
Operational Flight Trainer (OFT) (see Figure 3)	Cockpit (pilots) Motion base Visual system Aero Model
Sensor Operator Trainer (SOT)	Cabin (sensor operators) Ocean Simulation Submarine target simulation
(OFT, SOT can be independent or coupled.)	
Acoustic Trainer (AT) (4) SOTs (Can be independent or coupled.)	Similar to SOT above
Mission Training (see Figure 4)	Combines 2 WSTs in 1 Problem World
Tactical Team Trainer (TTT) (2 aircraft per TTT)	Limited Cockpit Active Tactical Data System Instructor plays Sensor Operators roles Tactical Environment simulation 2 aircraft may be independent or integrated in 1 problem world

6.2 One authority manages Aircraft and Trainer Suppliers

Since trainer designs should use aircraft common equipment (ACE) where possible, the Prime provides a single authority to specify, qualify, procure, test, accept and allocate the supplies.

Data Transfer: The prime has the responsibility to fulfill the aircraft requirements and integrate aircraft component suppliers into a system. Therefore, the prime normally writes the component requirement specifications, interface requirements, and acceptance criteria. This information is critical to the trainer design engineers. It is essential for accurately incorporating these components into the training environment. Using a third party trainer supplier would require the customer to be responsible for and to orchestrate transfer of data between aircraft component supplier and trainer supplier. This requires the Customer to promote Non-Disclosure Agreements (NDA) between the two companies. The

prime motivates each supplier to enter into NDAs and takes responsibility for accuracy and timeliness of the data.

Procurement of Aircraft Common Equipment (ACE): As the aircraft manufacturer, the prime is required to contract with suppliers to provide aircraft components. The CV-Helo trainer manufacturers used many aircraft common parts. It was relatively easy for the trainer parts to be "coat tailed" on existing ACE purchase orders. This provided the following advantages:

Economy of scale (lower cost with larger volume).

Reduced time to implement a Purchase Order with ACE supplier. (Do not need to competitively bid small quantity order, negotiate cost, schedule and Terms and Conditions).

The prime may be able to reallocate critical assets.

Fully qualified ACE used on the trainer is accepted using identical acceptance criteria as the aircraft. The configuration identities (part number and software load) are identical with the aircraft.

In the dual role of aircraft prime and trainer prime, Sikorsky understood the significant benefit to the customer in making the Automatic Flight Control System Computer (AFCSC) common for aircraft and trainer applications. Historically, special software had to be incorporated into the AFCSC to use it in a trainer. With the full cooperation of the aircraft engineers, the SH-60F AFCSC was redesigned to be both aircraft and Trainer compatible. The Trainer requires "Trainer freeze", restart, reinitialize normally, and reinitialize to a special "Initial condition". The AFCSC incorporated these special effects to allow its use in the Trainer and in the aircraft without Trainer Peculiar Software. The AFCSC automatically senses its environment through multiple redundant software and hardware sensors.

In some historical situations, the Trainer Program Manager has lost assets to support aircraft delivery. On the CV-Helo program, the opposite was the case. Aircraft Common Equipment was borrowed from aircraft allocations (on the same contract as the trainers), and given to the trainer. This reallocation was a critical factor in delivering NAS JAX trainers on schedule.

6.3 Commonality of Parts (Aircraft and Trainer) Minimizes Inventory Spares and Logistics Data

Use of aircraft common equipment in the trainer configuration allows the customer to have a single inventory item, rather than one for each application (trainer and aircraft). Non-recurring design costs for the trainer unique (simulated item) are not required. The life cycle costs associated with supporting one rather than two sets of inventory items is significant. Common software configurations and common data items are major cost minimizing drivers. One group of I-level and D-level data, tooling, and test sets is required. Navy inventory from the trainer can be exchanged with components from aircraft stores during maintenance. The trainer ACE can be repaired and returned to aircraft spares stock.

6.4 Aircraft Engineer to Trainer Engineer Communication

The trainer design engineer typically (and appropriately) desires much more data describing the aircraft system than is available. To minimize the filtering of information, the trainer suppliers were asked to identify any aircraft data that they required before the trainer contract was signed.

Early in the program, the trainer engineers visited the SH-60F Hardware/Software Integration Facility (HSIF). The HSIF provides a hot bench for testing tactical data system components. The HSIF provided the trainer engineers with their first live demonstration of the Tactical Data System.

Aircraft Engineering Change Proposals are routinely routed to the prime's Trainer Engineering to determine applicability of the ECP on the trainers. Many ECPs are not training significant. Some ECPs are recommended for incorporation into the trainer. The close ties between aircraft and trainer engineers minimize the time to incorporate ECPs into the trainers.

6.5 Acceptance Criteria

A critical concern for any Operator Trainer manufacturer and user is the acceptance criteria. There have been numerous instances when trainer deliveries have been delayed because the acceptance criteria was in the hands of the acceptance pilot (literally). Communicating what the pilot finds acceptable (what feels right) to the design engineer can be an arduous, time consuming effort. One of the more esoteric areas is in the Digital Control Loading requirements. Digital Control Loading employs a hydro-mechanical-software system to simulate the control loads on the pilots' hands and feet. The force/position/velocity experienced by the pilot in the controls provides significant training cues to the student and is a challenge to the design engineer.

In order to provide early definition of the control loading requirements, Sikorsky provided an aircraft to the trainer design engineers, who collected the data. This data was then made part of the criteria for acceptance. During inspection, this data provided discrete acceptance criteria for the control loading system.

Because the SH-60F aircraft is a derivative of the SH-60B and UH-60A (Blackhawk), little flight test data was collected for the SH-60F. Sikorsky had collected significant data on the predecessor aircraft. Through close cooperation between the Navy test pilots, Sikorsky test pilots and aero modeling engineers, and Reflectone engineers, the historical data was analyzed in depth. From this large amount of flight test data, the trainer aero model criteria was defined early in the program.

The above aero and control loading source data was made available to the trainer designers early in the program. Significant cost and schedule drivers were avoided because this data was available early in the program and prior to first flight of prototype aircraft.

6.6 Minimize Government Furnished Equipment (GFE) and Government Furnished Information (GFI)

One of the most often used reasons for contractor excusable delivery delay is late GFE and/or late GFI. By employing the prime, GFE, including Support Equipment, requirements were reduced to zero. No GFE was provided under the contract for CV-Helo trainers. By employing the prime's aircraft data configuration definition, aircraft handling data, and the aircraft itself, GFI requirements were reduced to classified submarine target data, ocean temperature curves, and some visual scenes data. Thus, customer risk is greatly reduced while design information is provided when needed.

6.7 Employ Aircraft Tooling

The hardware Maintenance Trainers, such as the Composite and Avionics MTs, employ a large number of aircraft common parts. Parts such as the aircraft upper deck and fuselage components are assembled in the same final assembly production line as the aircraft. Tooling required for the aircraft is used for the trainer. To facilitate production control and planning, each trainer in the assembly line is assigned a dummy aircraft tail number.

6.8 Training Begins Early in the Program

The delivery of trainers allowed qualification and training of pilots and maintainers in a timely manner to support HS-10 readiness. These trainers reflected an aircraft configuration which was only a few months older than the configuration of the fielded fleet aircraft. This concept allows the trainer to be on-site in time to begin training much earlier than if the trainer design had been delayed to reflect later aircraft configurations. A trainer upgrade is underway to bring trainer configuration up to the current fleet aircraft configuration.

7 "BOUGHT FROM THE PRIME" ADVANTAGES DECLINE WHEN....

7.1 Aircraft Design is Mature

A mature aircraft design means that data describing the aircraft configuration is stable and readily available to any interested party. Under this condition, the communication link between aircraft designer and trainer designer is no longer vital to meeting a tight schedule.

7.2 GFE/GFI is Readily Available

When aircraft common equipment, i.e. GFE, and Government Furnished Information (GFI) are readily available from the Government, the benefit of using the prime's pool of equipment and data declines.

7.3 Simulated Not Stimulated Aircraft Equipment Used in Trainer

The design philosophy of employing Simulated Aircraft Equipment rather than Stimulated (Aircraft Common) Equipment removes the prime's contribution of providing a readily available pool of aircraft boxes. Simulated equipment provide the following trade offs associated with aircraft equipment:

Increases Non-Recurring Costs

Decreases Recurring Costs

Facilitates simulated malfunction insertion into the box

Significantly drives up cost and schedule required to reflect aircraft ECP (Engineering Change Proposal)

8 COST SAVINGS

The following, which were discussed above, can be considered in the cost savings equation for buying from the prime:

Program and Inventory cost of new aircraft waiting for trained personnel is minimized. Major delays in training commencement may jeopardize the aircraft program, as well as the trainer program.

Use of Aircraft Common Equipment in the trainers minimizes costs of the following:

- Initial box procurement
- Non-recurring Engineering
- Inventory
- Maintenance
- Initial and life cycle data
- Upgrade (ECPs)

Customer management in securing GFE and GFI.

Supplier compensation for delayed GFE and GFI.

Customer management of ECP incorporation.

Providing trained crews and maintainers early in the life of a new weapons system. (This is difficult to quantify, but a major consideration.)

The above cost savings outweigh the perceived extra costs (overhead) that may be encountered in procuring third party trainers through the prime.

9 LESSONS LEARNED

9.1 Background: Several changes to the aircraft software were made subsequent to Trainer PDR and CDR. Trainer delivery was delayed several months in order to incorporate these aircraft changes.

Recommendation: When trainers support newly developed aircraft, the contract should provide a vehicle to allow for a Block Upgrade after trainer delivery. The Block Upgrade would best be served with a cost plus type contract because the extent of the Block Upgrade is impossible to determine several years in advance.

9.2 Background: Simulated aircraft components were permitted to be employed in the Operator Trainers. This is appropriate because some instruments (such as the air pressure driven airspeed indicator) are quite expensive to stimulate. These instruments also have mature configuration definition. Simulated components which are likely candidates for aircraft Engineering Change Proposals (ECP) require significant non-recurring engineering when the ECPs are incorporated into the trainer. These components, such as the Armament System Controller (ASC), are complicated to simulate and are schedule drivers during trainer upgrades.

Recommendation: Simulated instruments should be limited to those which are unlikely ECP candidates. Aircraft common equipment, such as the ASC and Communications System Controller (CSC), should be employed in the trainer. This will facilitate incorporation of aircraft ECPs.

10 CONCLUSION

Where training of aircraft crews and maintainers is required soon after delivery of a new aircraft weapons system, there are significant cost and schedule benefits in procuring the training devices from the

aircraft prime. Communication delays between the aircraft designer and the trainer designer are minimized. The need for GFE / and most GFI can be avoided because of the prime's inherent custody and interest in this material / data. Given that aircraft common equipment (ACE) (rather than simulated equipment) provides the best design approach for trainers, the prime is best postured to provide ACE.

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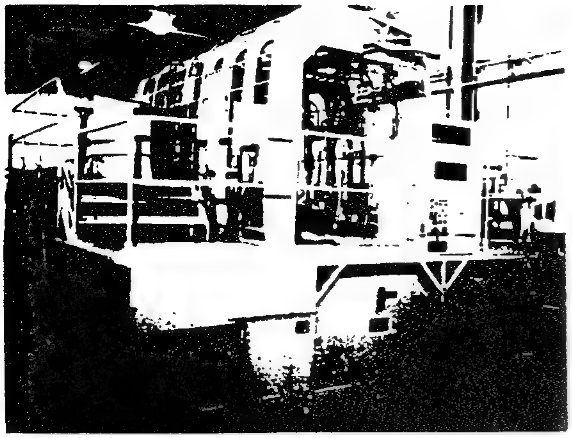
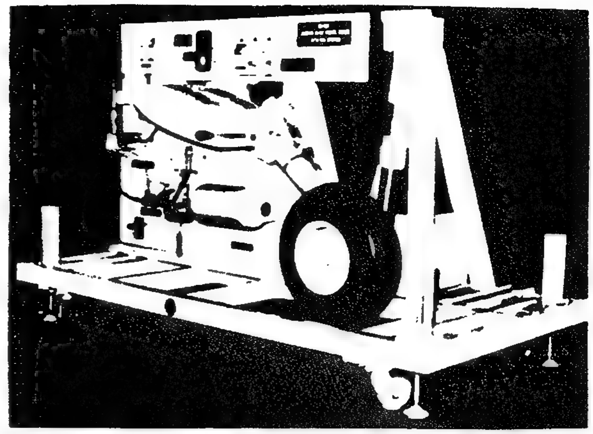
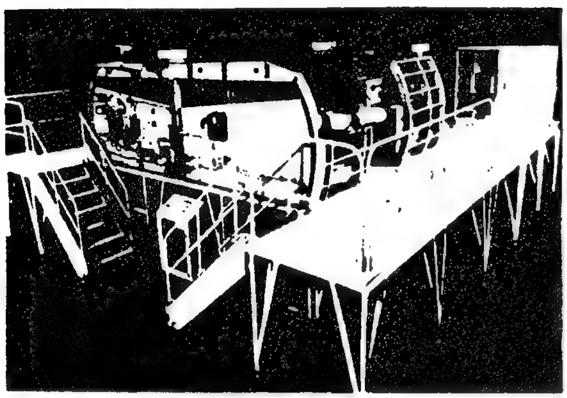


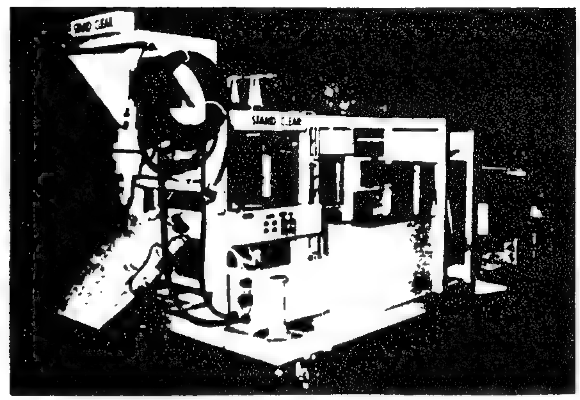
MH-53E WET FUEL SYSTEM MT



LANDING GEAR MT

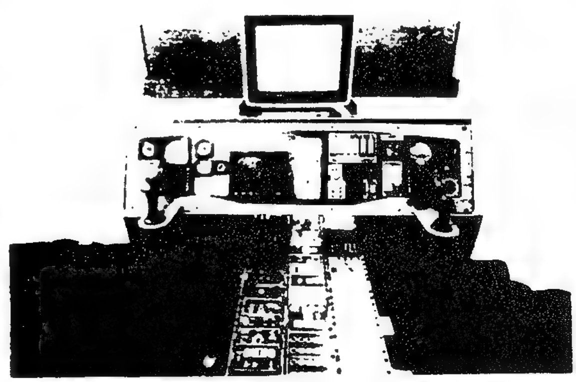


AVIONICS MT



AFCS MT

FUEL SYSTEM (PANEL) MT



TACTICAL TEAM TRAINER

Figure 5 Typical SH–60F Operator and Maintenance Trainers

INTEGRATED TRAINING ENVIRONMENT: CONCEPTS AND RESEARCH DIRECTIONS

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ABSTRACT

In this paper, we propose to incorporate elements of education and training in a seamless architecture that would promote enhanced training effectiveness in this era of shrinking budgets. Specifically, we will discuss interdependencies in the methods used in the classroom educational environment and the hands-on training environment. We will examine how analogous functions of the educational and training environments can be integrated to facilitate seamless training in a cost-effective manner. For example, we will discuss how the instructor console in the educational world may be combined with the capabilities of the master control console and command centers in the training world, and how the brief and debrief capabilities of the training world can provide valid simulation to review lessons learned in the classroom world. In bridging educational and training environments, we will identify technologies, such as networking and artificial intelligence, that can enhance training effectiveness within those environments. We will also discuss future research directions to address the overall training problem of merging educational and training environments.

INTRODUCTION

Typically, the training environment consists of a sequence of discrete activities (see Figure 1): (1) classroom lectures, (2) hands-on training in a lab containing a simulator, and (3) hands-on training with the actual tactical system through field exercises or embedded training. The classroom environment is a typical lecture environment that is focused on instructional presentations using media devices such as an overhead projector, a VCR, and a blackboard. The lectures are reinforced by hands-on training in a lab containing simulators that typically do not completely emulate the tactical system. To augment classroom lab exercises, debrief activities are, then, used to highlight and reinforce the devised training objectives. Following these schoolhouse activities, skill development continues with on-the-job training through field exercises and normal daily use.

Presently, the bulk of training is done using the real tactical system, whether it be from normal daily use, planned field exercises, or use of embedded training capabilities. Future efforts must concentrate on providing training improvements that will move the bulk of training into the classroom and simulator lab and will result in overall savings

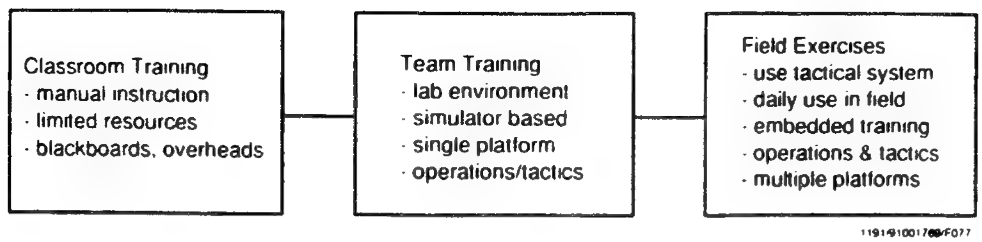

Figure 1. Traditional Training Environment

to the Department of Defense (DoD) by reducing usage of the tactical hardware. Our approach will form a comprehensive training environment that will not only enhance training, but also facilitate access to training by a greater number of individuals.

To achieve the stated objective, an integrated structure (see Figure 2) will be explored for training groups (classroom), individuals (computer-based self-instruction), teams (team trainers), and groups of teams (simulated battlefield, which can include land, air, and sea forces). To transfer a greater percentage of training activities to the simulator world, each trainer requires realistic simulations, connectivity to a network of trainers for simulated field exercises, and training curricula ranging from the individual level up to the highest field command level in each of the four activities above. Critical to the cost-effective seamless training environment solution is the ability for easy movement into and out of each training activity through common features and to easily access each activity through networking remote locations and low-cost individual training devices

In the following sections, we will discuss conceptual requirements for the proposed integrated training environment that entails classroom training, computer-based autodidactic (self-instruction) training, team training, and battlefield training. For each training activity, we will identify existing technologies that are needed to address the conceptual requirements. We will discuss the critical role of artificial intelligence and networking as two areas of technology, that are required to enhance training effectiveness. We will conclude with

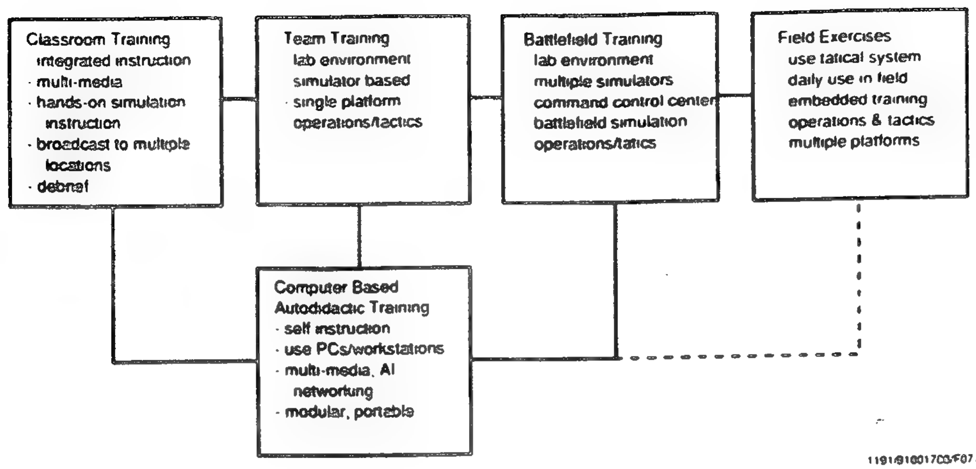

Figure 2. New Training Environment

some remarks regarding future directions for training systems development. No DoD standards discussions are included, but standards like those for operating systems (POSIX, Portable Operating System Interface for Computer Environments), interactive courseware (ICW, Interactive Courseware), logistics (CALS, Computer-aided Acquisition and Logistics Support), and communications (GOSIP, Government's Open System Interconnect Profile) are expected to be used for these existing areas and to be established for new elements of the integrated training environment.

TRAINING ENVIRONMENT CONCEPTS

Conceptual requirements for the proposed integrated training environment are addressed by the four training types as identified above: Classroom Training (groups), Computer-Based Autodidactic Training (individuals), Team Training teams), and simulated Battlefield Training (groups of teams from land, sea, and air). The integrated training environment requirements are intended to provide common structures and tools across the four training activities, to improve access to training for individuals and groups, and to increase training realism. In addition, such an integration environment provides hands-on training starting in the classroom, and provides connectivity to allow large-scale networked battlefield simulations.

CLASSROOM TRAINING

A requirement to incorporate learning systems into the standard classroom provides a foundation for training improvements. The

purpose of learning systems is to enhance instructor authoring and delivery using the integration of various medias. The basic elements for learning systems include: (1) training analysis and courseware design; (2) courseware development, delivery, and evaluation; (3) training management; and (4) communication. Current learning systems provide instructors with efficient curriculum design and development, and easy access to text, graphics, audio, animation, and full motion video. Learning systems also provide interaction with the student, control of classroom information, access to available resources, and communications among all personnel involved in a training system. Enhancing the learning systems to allow integration of tactical system simulations provides a foundation for hands-on training in the classroom. Classroom Training concepts intended to meet these needs are discussed in the following sections:

INSTRUCTOR PRESENTATION CENTER: An Instructor Presentation Center (IPC) is a device that integrates various types of media under computer control. It provides an instructor with the ability to smoothly present material from vastly different media including overhead foils; excerpts from books, magazines, and papers; videotapes; simulations of the tactical system; audio tapes; laser discs; computer-generated displays; student inputs; and more. The IPC contains controls to present material, and to communicate with student stations and remote training sites.

SIMULATION: The classroom includes the integration of simulations from the lab team trainer into the classroom presentations using an inexpensive hardware platform. The simulations are responsive and interactive, providing hands-on training in the classroom.

STUDENT STATION (SS): The classroom includes student stations that provide a full spectrum of interactive exercises ranging from high fidelity simulations to true/false questions. The classroom student station and the device for Computer-Based Autodidactic Training share the same functionality within the integrated training environment.

NETWORKING: The IPC and the student stations are networked to provide the instructor the capability to activate an exercise simultaneously at each student station and collect responses from each student station. Provisions for student stations to share data are included to allow interactive training between multiple stations. Reduced training travel costs and improved access to training is accomplished by extending the classroom activities to remote locations through satellite or terrestrial networks. The classroom IPC is networked with the Team Training and Battlefield Training control centers for debrief activities.

ARTIFICIAL INTELLIGENCE (AI): The IPC provides the ability to collect student responses to exercises, analyze the responses, prepare statistical summaries on performance for feedback to students, and even allow simulated instructor feedback during class exercises to provide individualized computer-based instructional interaction that

can supplement the actions of an instructor. For simulation presentations, various controls such as target movement and reaction characteristics are automatically controlled by AI algorithms. AI algorithms are exploited wherever instructor workload can be reduced.

DEBRIEFING CAPABILITY: The IPC is capable of presenting debrief material following Team Training and simulated Battlefield Training exercises. The IPC and the Team Training and Battlefield Training control centers are connected to allow debrief materials to originate from each location.

COMPUTER-BASED AUTODIDACTIC TRAINING (CBAT)

CBAT provides an alternative to traditional classroom and lab training methods. Individuals can use CBAT to foster self-development outside the classroom and group training activities. This training can occur at a schoolhouse or a remote location, or while stationed on a large weapons platform. The requirements of CBAT include the following:

HARDWARE ARCHITECTURE: The CBAT host hardware supports a variety of training modes including basic operator training, interactive operator training, team training, tactics training, lecture presentation, and simulated battlefield training. The CBAT device is operational in a standalone, group, or classroom situation. It allows interconnection to other devices, and provides interaction with audio and video presentations. PCs or workstations offer a cost-effective solution that is easily transportable and expandable.

SOFTWARE ARCHITECTURE: The CBAT device can host a variety of software applications, both real-time and non-real-time, that exhibit modularity and portability to allow maximum reuse. A menu-driven interactive environment is provided to allow the user to select from a variety of training modes and specific training scenarios.

SIMULATION: The CBAT device can run real-time simulations with display presentations as contained in the Team Trainer simulator. This gives an individual student the ability to develop and polish skills outside the classroom or team training activities.

NETWORKING: The CBAT devices can communicate together in a classroom configuration or in groups that would operate as a subset of the tactical system. This supports both vertical communications to command centers and horizontal communications to peer simulators in a team as part of a distributed interactive simulation.[1]

ARTIFICIAL INTELLIGENCE: The CBAT device provides instructional feedback to the student. This is achieved with AI algorithms that act as an instructor by providing instructions, performance evaluation, and feedback to the student. The control of scenario parameters (that is, Semi-Automated Forces or SAFOR) in any simulation application are under AI control to release the student from activities that are not specifically related to the lesson goals. Interactive algorithms to

simulate supervisor and peer responses to the student's communications allow communications skill development with supervisors and peers.

LECTURE REVIEW: The CBAT device supports the incorporation of an "encyclopedia" of information for student retrieval. The information consists of text, video, and audio data integrated into recorded lectures and reference information which the student can recall.

TEAM TRAINING

Team Training encompasses training on tactical system simulators that involve a group of individuals assigned to a single weapons system platform, such as a tank, a helicopter, or a submarine. The requirements for Team Training include the following:

HIGH FIDELITY SIMULATION: The fidelity of each simulator is improved towards realism. The simulation of the environment, vehicles, and other objects and the more complete emulation of the tactical system are required.

ARTIFICIAL INTELLIGENCE: Each simulator includes expanded SAFOR capabilities with each simulated force, both friendly and unfriendly, having capabilities such as characteristic motion, detection, and decision making. The ability to monitor and analyze student performance is accomplished by the use of maturing AI technologies.

NETWORKING: The simulation architecture for future team trainers consists of a group of processors in a distributed architecture in which communications between processors, that contain functional components of the entire platform, are established to provide real-time interactive simulation. This distributed architecture is characterized by a high degree of modularity and portability that allows for ease in system extensibility. Each team training simulator is capable of communicating with other team trainers to allow multi-platform simulated field activities. Passive connections to a multi-trainer training session is permitted to allow a site to train separately using the field exercise scenario and events. In addition, debrief activities are supported by interconnecting the simulator with the classroom IPC.

BATTLEFIELD TRAINING (BT)

The objective of Battlefield Training is to provide an integrated environment for collective training at different organizational levels--such as platoon, company, and battalion-level units--to conduct tactical engagements in a combined arms battle simulation. The battlefield environment supports large-scale networking of a massive number of interactive manned simulators to participate in a war-gaming exercise. Additionally, Battlefield Training supports a viable semi-automated forces simulation that is capable of generating both friendly and opposing forces in a complex and realistic

operational setting using artificial intelligence. The requirements for Battlefield Training include the following:

BATTLEFIELD COMMAND CENTER: Battlefield Training is controlled from a command center that manages the simulation and identifies all simulator platforms participating in a given exercise, including those of SAFOR. The command center communicates appropriate SAFOR and environmental scenario events in real-time to each simulator in the training session with a common protocol, such as the DIS protocol. Similarly, each participating simulator communicates scenario events for its platform to the command center and other participants. The command center can conduct more than one battlefield training session simultaneously. Individual trainers can be upgraded with command center capabilities so that a unique site is not required to control small-scale battlefield training exercises.

MODULAR COMMAND CENTER INTERFACE: Each trainer is connected to the Battlefield Command Center. This interface is modular and interacts with the trainer similar to the other scenario control mechanisms within the trainer.

TYPES OF TRAINERS: The types of trainers that can be connected in a battlefield training scenario include all trainer platforms corresponding to the normal participants in a real world battle, where entities such as tanks, planes, ships, and troops would all be included in the exercise. Tactics training is provided at any level of field command and control. In cases when a level of command is not taking part in the exercise, the interactions with the command level are simulated.

ARTIFICIAL INTELLIGENCE: To complement the AI requirements in Team Training, the use of SAFOR in BT allows for the command, control, and communications of a large number of platforms and their associated weapon systems. User-friendly interfaces are provided to facilitate operator's control of the SAFOR system. As a minimum, SAFOR monitors and evaluates all unit behaviors, both friendly and foe, and assesses the battlefield situations to react dynamically as events unfold.

NETWORKING: The BT environment consists of a large number of networked simulation devices (team trainers, CBATs, and so forth) interacting within a computer-generated environment. This environment ranges from battle theatre down to battalion level. The trainers interchange state information that enables the individual simulators to recreate the dynamic effects of the simulated environment. Means are provided to support the updating of databases for various scenarios on the simulation devices.

COMMON SIMULATED VEHICLES/ENVIRONMENT: The vehicles and environment simulated in BT are consistent with their simulations in each of the team trainer simulators.

TRAINING ENVIRONMENT CONFIGURATION

The requirements above are a basic set of needs for an integrated training environment. In this section, we identify existing technologies needed to fulfill the requirements for each training activity. Special focus is given to artificial intelligence and networking.

CLASSROOM CONFIGURATION: The classroom configuration consists of a group of personal computers (PCs) or workstations with their associated peripherals, connected in a network, and a group of presentation devices such as an overhead projector, video player, and audio player as part of the IPC. The IPC and the student stations are each composed of a PC, a workstation, or a network of PCs and workstations depending on the processing requirements for the application. Each station is connected on a local area network (LAN) to allow communications within the classroom (see Figure 3). The connection to remote locations for transmission and receipt of classroom sessions can be through wide area networks (WANs), telephone lines, or satellite communications (see Figure 4).

The IPC contains a student station integrated with media peripherals, so that the instructor has all the capabilities of a student, plus all of the capabilities required to control the class presentations. The application code in the IPC provides the instructor with a menu-driven control panel for easy management of the class flow. The IPC provides the capability to develop a class scenario of events that will be sequenced through simple "next event" commands. The instructor is provided with the ability to interject the flow with a different event at any time (that is, revisit material presented earlier). The events in the class scenario include commands to control the various media

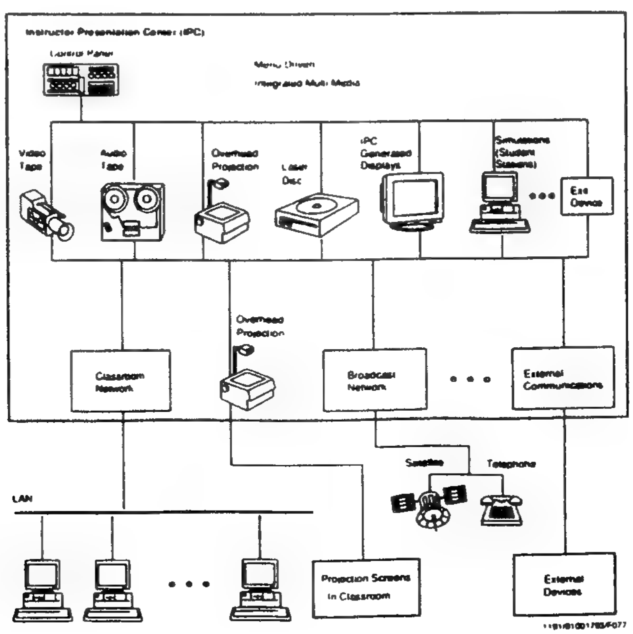

Figure 3. Classroom Configuration

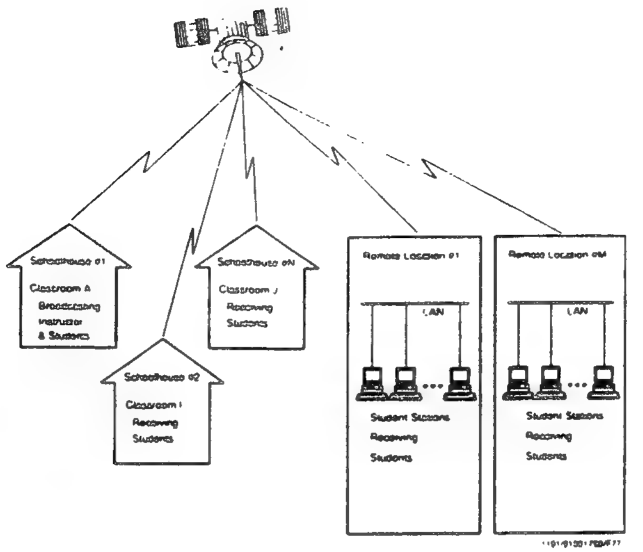

Figure 4. Long Distance Training Configuration

peripherals attached to the IPC control computer. The IPC activates each device as an event requires the material contained on the device. The output is shown on overhead projection for the entire class to see, or through presentation on each student's display. The ability to route a student's input to an overhead projection device is also under the control of the instructor. Since a student station is part of the IPC configuration, the instructor can provide real-time or canned exercises and explanations using tactical system simulations. The IPC can capture data from the student stations network to allow real-time presentation of student responses to exercises. The IPC can also connect to the tactical system simulator to allow silent exercises (those that do not affect the operations of the simulator training) in the classroom or debrief events, so that the scenario data from the simulator can be used to drive the simulations in the classroom.

The long distance training configuration allows connection to another classroom or just a set of student stations with a display station for viewing a classroom broadcast. The ability to communicate from the remote locations with questions and exercise responses is essential. This is accomplished by treating the remote locations as just an extension of the users on the student network. Encoding and decoding capabilities are included when security requires it.

STUDENT STATION (SS) CONFIGURATION: Computer-Based Autodidactic Training is accomplished through the student stations. The CBAT student stations are used in the classroom as described above or individually by students outside the classroom. The CBAT student

station configuration is a PC, workstation, or a combination of the two connected together acting as one device (see Figure 5). The processor, one or more displays, a keyboard, and a mouse are needed. Memory and disk storage additions, printers, overhead projection, and network communications are included depending on the specific application.

The processing power included in the SS is dependent on the required simulations. The intent of the SS is to allow subsets of the full tactical system simulator to run on the SS. With this, hands-on training is provided to students in the classroom at the SS. Students can reinforce the classroom lectures with hands-on exercises on the SS out of the classroom. The application code in the SS includes intelligent computer-aided instruction to take the place of the instructor. With this, the student is provided with the instructions to conduct self-paced study exercises and receive help and feedback to responses. Various aspects of training are included in the CBAT SS. Examples of options to select from are storyboard lecture material, canned exercises (for example, Q&A or simulations), interactive simulations (for example, emulation of tactical system), and prerecorded lectures (that is, via multi-media capability). For some systems, the SS is not able to present the same level of fidelity as the tactical system simulator because that function would require expensive special purpose components in the simulator.

The inclusion of artificial intelligence software for intelligent computer-aided instruction, SAFOR simulation, and natural language

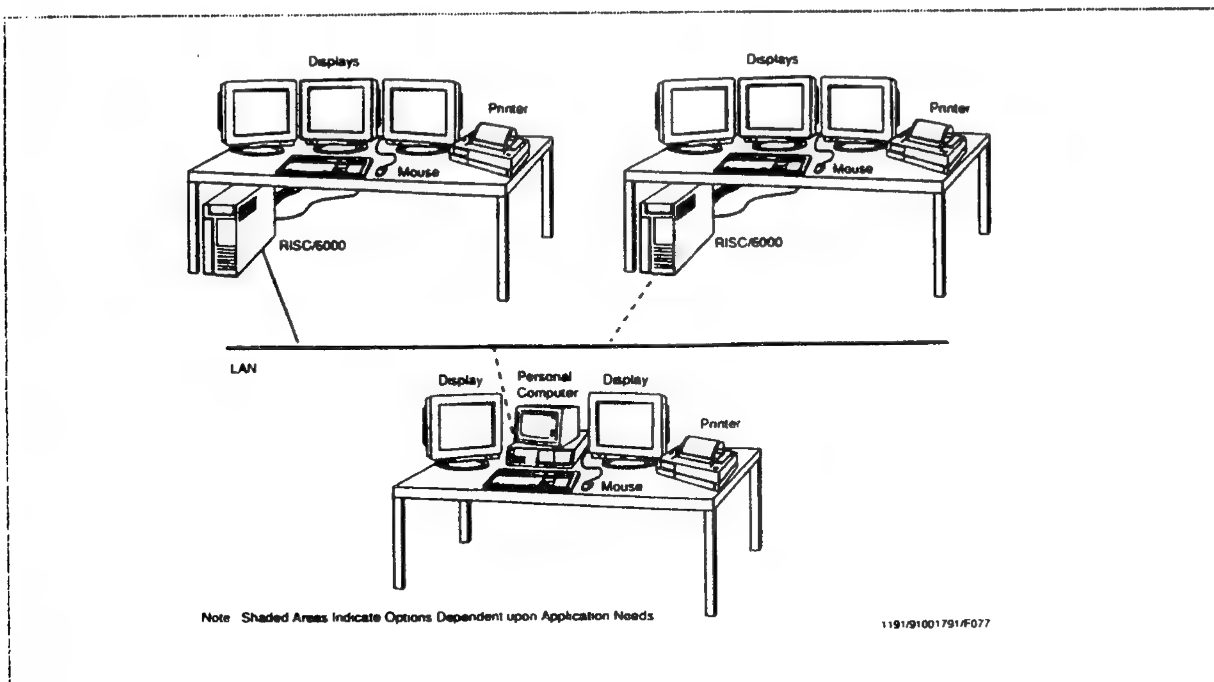

Figure 5. Student Station Configuration

processing are critical to the usefulness of a SS. This issue will be discussed later in the AI section.

TRSM TRAINING SIMULATOR CONFIGURATION: The configuration of each simulator is dependent upon the tactical system being emulated. However, the development of its configuration will have to include the needs of the SS to facilitate an integrated training environment. This equates to the development of modular, portable code to be used in the SS simulations. Without this, the cost of rewriting simulation code for the SS will probably be prohibitive. Also, interfacing code to the classroom is part of the simulator's design. The interfaces to the classroom includes scenario events as described above or replication of student and instructor displays. The connections to accomplish this are either through direct connections from the classroom to the simulator or through a network.

Artificial intelligence software for automated control of forces plays an important role in presenting a common appearance to the users. Common software controlling the automated forces is reused from the simulator to the SS and classroom to guarantee common force behavior and the ability to port scenarios between training activities.

BATTLEFIELD TRAINING CONFIGURATION: The configuration for Battlefield Training consists of the tactical system simulators and tactics trainers playing an active role in the BT exercise, a BT Command Center (BTCC), and any remote location connected in a silent role to observe the exercises (see Figure 6). The configurations for the locations playing either an active or silent role are covered above as simulators or student stations, with the exception that the hardware required to connect into the BT network is required along with the interfacing software. The work of the BTCC is accomplished using a network of workstations with an appropriate number of displays, network/communications ports, and peripherals. The BTCC has the appearance of a mix between a communications control center and an instructor's control console (as used in a typical simulator). The BTCC operators use displays to set up and manage the participants of the training exercise and enter SAFOR forces to simulate opposing or friendly forces not represented by participating locations. The typical capabilities of an instructor's command console and the capabilities of the IPC are integrated in the BTCC to provide debrief and instructional activities to participating locations. In this case, the BTCC does not provide simulation replay for a particular site. Instead, scenario events are provided as in the BT exercise.

ARTIFICIAL INTELLIGENCE

The field of artificial intelligence (AI) is finding a considerable number of applications in many complex military problems as the complexity of weapon systems increases. AI, in itself, is remarkably broad and rich in the types of techniques and methodology that it can bring to address the military problems and, in particular, military training problems.[2] It is not within the scope of this paper to

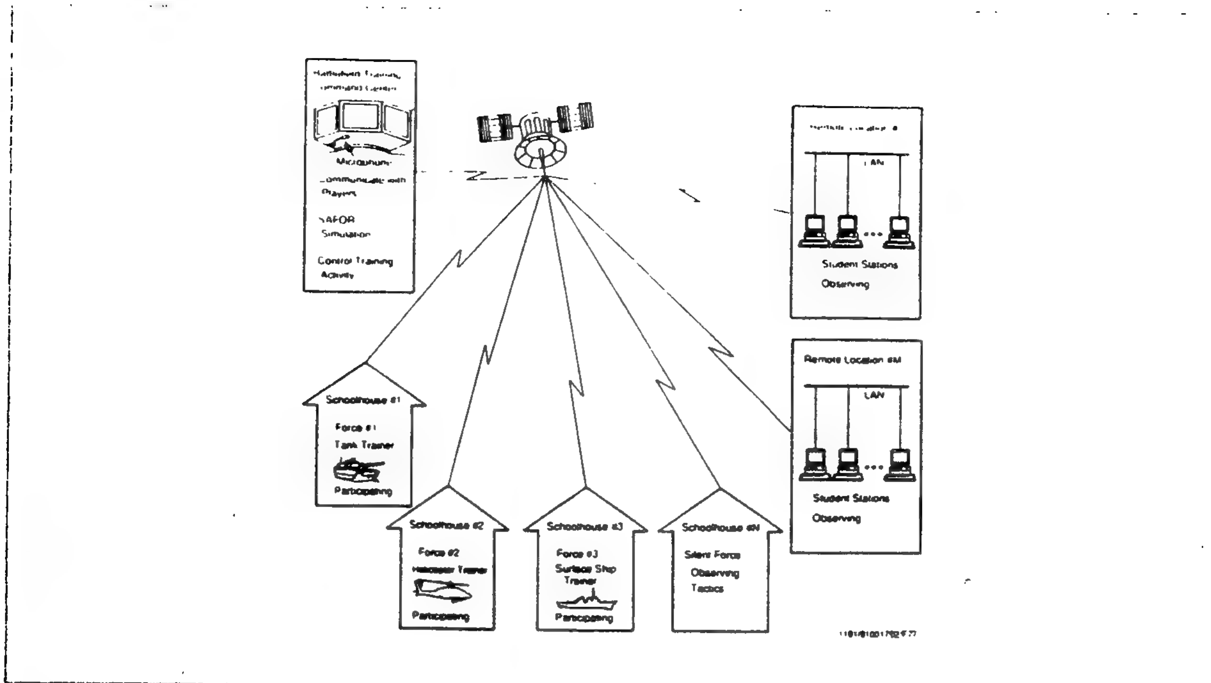

Figure 6. Battlefield Training Configuration

present a detailed description of the technology, but rather to give a brief overview of the different types of AI technologies, both proven and maturing technologies, and to offer how these technologies may solve the problems facing the training community today. Specific attention is paid to addressing the AI requirements as portrayed in previous sections.

EXPERT SYSTEMS AND KNOWLEDGE-BASED SYSTEMS: Of the various types of AI systems, expert systems and knowledge-based systems technologies are widely perceived as the AI technologies with the most potential for the development of near-term applications. Much effort has been committed to use this potential in emulating human expert behavior modeled after procedures and decision-making heuristics as employed by human experts. In the following, we discuss a number of AI research areas revolving around expert systems or knowledge-based systems technology:

1. Intelligent Computer-Aided Instruction

A class of AI systems that has recently received much attention is intelligent computer-aided instruction. ICAI is devoted to the development of instructional systems that have a true knowledge base of their teaching domain. These systems offer the potential for intelligent systems to provide adaptive and effective instruction to students. In a classroom environment, ICAI systems contain the knowledge required to generate the correct answer, and therefore can hypothesize about what aspects of this knowledge the student

is lacking so that a strategy for instructing the student can be formalized. Hence, the collected student responses to exercises can then be analyzed and fed back to the students during class exercises. ICAI also supports supplemental self-training external to the classroom as conducted in computer-based autodidactic training by providing automated instructional feedback is provided to the student.

2. Semi-Automated Force (SAFOR) Simulation

The application of knowledge-based or expert systems can also be of great benefit in simulating intelligent friendly and opposing forces (SAFOR) to take part in a simulated battlefield environment. SAFOR simulation systems are equipped with an appropriate domain knowledge base that includes tactics, doctrine, and terrain knowledge to dynamically adapt or react to a simulation as new events unfold. SAFOR controls target movement and characteristics or behaviors of the semi-automated platforms in a simulated scenario presentation as in the classroom, or CBAT training environment. In team training or battlefield training, SAFOR supports an increasingly larger number of semi-automated platforms that can dynamically respond and react to a changing environment.

NATURAL LANGUAGE PROCESSING: An important area in AI that can be used to address the man-machine interface is natural language processing. Natural language processing refers to machine understanding of the language that people use in a normal discourse. Two general areas of research are: (1) understanding of written text, and (2) understanding speech.

Whether one is in a classroom, CBAT training, team training, or battlefield training environment, natural language processing facilitates the interaction between user and system. In a classroom environment, the capability to carry an active natural language dialogue expedites the process of course delivery and allows the student to focus on the course materials and not the syntax by which to communicate with the system. In CBAT training, this technology greatly facilitates the monitoring of student performance and instructional feedback in terms of natural language. In a team training or battlefield training environment, natural language processing simplifies the control and communication processes of SAFOR simulation and, thus, can immensely improve human performance.

AUTOMATED PLANNING: Automated planning refers to the automated ability to define a sequence of actions (such as a plan) to achieve a specific goal or mission. Much research in AI has been dedicated to the development of systems for generating action plans for various kinds of agents faced with complex and conflicting goals. Automated planning forms a very crucial part of SAFOR simulation in that it allows the system to plan or readjust its plan to achieve a mission. The merging of automated planning technology and that of game playing

(strategy) technology greatly enriches the adversarial nature of SAFOR simulation. This enhances the reactive power of SAFOR and, therefore, provides a more realistic opponent for all training environments.

DISTRIBUTED AI: Distributed AI is the study of how a group of individual intelligent agents can combine to solve a difficult large-scale problem. This concept is modeled after a network of experts required to interactively solve complex problem domains by means of coordinating and cooperating within various organizations.[3]

A maturing area of distributed AI technology is blackboard technology. A significant amount of work on data fusion[4] has been performed using this technology. Here, the blackboard serves as a knowledge base wherein information collected from diverse sources are interpreted and system behaviors are monitored to perform situational assessment. Results from this analysis can also be used for inferring likely consequences of a number of given situations. This is highly applicable in conducting classroom instruction or computer-based autodidactic training where data is gathered from students, data analysis is achieved, and student performances are monitored and evaluated. Similar situations arise in a team training or battlefield training environment where battlefield situations must be assessed. This means that all observable unit behaviors are monitored and evaluated to decide how to conduct the battle forces. In addition, this AI methodology can be used to monitor and analyze student performances by correlating student responses with situational information residing on the blackboard. Blackboard technology can also be employed as a decision-aids tool for a SAFOR operator facing extremely complex situations. In such circumstances, this tool may alert operators to possibly critical observations that support the conduct of both analyses and operations.

NETWORKING

The network requirements across the training environments (classroom, computer-based autodidactic, team, and battlefield training) have many similarities. This section concentrates on the network services provided by the transport mechanisms, such as broadcast, multicast, and transaction. Even though the user's applications vary across the training environments, there are similarities in the application's interface to the transport mechanisms that enables network interoperability.[5]

BROADCAST SERVICE: A broadcast service activates the simulation exercises simultaneously for the students and receives responses from the students' interaction with the exercises. The broadcast service is a datagram or message service that sends messages to all nodes on the physical network and does not require responses or acknowledgements to ensure reliability. The redundancy in the application combined with the reliability of the physical networks ensures accurate communications between the simulations. The

broadcast service also supports the requirement for the students to exchange dynamic changes in their simulations when they interactively participate in a simulated exercise. The data fields within the broadcast messages contain application information that describes the dynamic changes of the simulated environment. These data fields are Distributed Interactive Simulation (DIS) protocol data units (PDUs) that are being standardized in the Committee for the Interoperability of Defense Simulations.
Distributing the team training functions for a single platform has similar communication requirements as the student interactions in classroom simulations. Although the information within the broadcast messages may be more detailed to support the team training functions, the network broadcast service would be the same in delivering the messages to the multiple functions. The information needed for the distributed team training applications is provided within the DIS PDUs. The broadcast messages are received by all simulation applications, and the applications determine if a particular message is needed for the function being simulated. The applications discard any information that is not intended for its function, even if it is a complete PDU. Since there are a limited number of functions within a single platform, this filtering of messages at the application is easily satisfied.

MULTICAST SERVICE: Like the interactive student stations and the distributed team training functions, the distributed battlefield simulation also has multiple applications exchanging simulation information. The DIS PDUs contain information to dynamically update the battlefield simulation among multiple simulated applications. In this case, the multiple applications consist of dynamic entities in a battlefield such as tanks, planes, ships, and soldiers. The battlefield simulation involves a large number of interacting entities requiring a large number of messages to be received and processed from the broadcasting entities. Having to receive this large number of messages causes a processing bottleneck for the host simulation. Thus, the battlefield training problem needs a capability to filter the broadcast messages at the network interface. A LAN addressing technique that enables filtering of unwanted broadcast messages at the network interface is called the multicast service. The multicast service is a subset of the broadcast service with the additional capability of providing a media access control (MAC) addressing format that is used by network interfaces to filter unwanted messages. Using the multicast service, the host only receives the messages that are destined for its applications, alleviating frequent interrupts of unwanted incoming messages. The multicast service also enhances classroom training by broadcasting the student responses to an IPC group address only, so that each student's application is not getting every other students' responses.

STREAM SERVICE: In addition to the datagram services, the training environments also need connection or stream services. These services are used to enable the exchange of large blocks of data in an ordered fashion when there are no critical timing requirements. For example, the classroom environment needs to exchange databases

that contain the course lecture between multiple widely distributed sites. Like the classroom environment, the team training and battlefield environments also have databases containing the static information that is used with DIS PDUs to create the training scenarios. These databases can be exchanged before the class or training session begins when there is plenty of time to establish connections and communicate the large blocks of data. This service is also needed for instructor and student requests and responses on an individual basis. By having the connections performed at initialization before a class begins, this service provides a reliable and efficient method of individual interaction between the student and the instructor.

NETWORK TECHNOLOGIES: Future network technologies are being researched that will enhance the distributed training environments. Asynchronous Transfer Mode (ATM) is a future network technology that will significantly enhance the ability to satisfy the above service in a real-time high bandwidth means. ATM is a packet switching technology compatible with the data transmission technologies used in today's LANs, and will enable more efficient routing mechanisms between WANs and LANs. By using similar network services and evolutionary network technologies, the training environments can become integrated to provide more effective, seamless training.

FUTURE DIRECTIONS

We have covered the integration of classroom, self-paced, team, and battlefield training activities. An extension of this integrated training environment includes embedded training in the tactical system and training involving a combination of tactical systems with the team training simulators. We must address how to integrate the events of a tactical system into a training exercise for a simulator and how to inject the effects of the scenario from a simulator into the operations of a tactical system. A subset of this concept involves providing embedded training in the tactical system which has common links with training provided by the simulator.

SUMMARY

Training improvements are realized with an integrated environment that consists of classroom, autodidactic, team, and battlefield training. This integrated environment consists of existing technologies--such as AI, networking, workstations, and multi-media--and it can grow as the technologies grow. The integrated training environment relies on software modularity and reuse practices to provide more overlap in each phase to smooth the transition between training devices for personnel. The effectiveness of instructors is enhanced by bringing hands-on exercises into the classroom, by extending instruction to include the use of the CBAT student stations, and by broadcasting the training lectures to other locations. Thus, the integrated training environment provides a better educational environment for the student and allows training to be

provided to more students without increasing the number of instructors.

ACKNOWLEDGEMENTS

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Generic Computer-Based Training System: A Concurrent Object-Oriented Programming Implementation

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ABSTRACT

The requirements for a Computer-Based Training (CBT) system have evolved and were derived from three major activities conducted by IBM. They include product development, industry-wide CBT software evaluation studies, and program experience. The results from these activities directed the development of the Generic Computer-Based Training (GCBT) system. The GCBT system was developed by IBM Manassas to provide a multimedia authoring environment for interactive courseware (ICW) development and to deliver the courseware in a networked or stand-alone computer-based training environment. By using Concurrent Object-Oriented Programming (COOP) in the GCBT system, we achieved modularity and code (courseware) reusability, which are inherently the byproducts of COOP. The GCBT architecture provides a generic framework for integrating the best of breed Commercial-Off-the-Shelf (COTS) products into the GCBT system. In this paper, we will discuss the architecture and the operational capabilities of the GCBT system.

INTRODUCTION

Computer-Based Training is a powerful and effective tool as demonstrated in numerous applications throughout the training industry. The Generic Computer-Based Training System was developed by IBM Manassas to provide a multimedia authoring environment for interactive courseware development and to deliver the courseware in a networked or stand-alone computer-based training environment. By definition, CBT supports the delivery of curriculum to students in a one-on-one environment. This environment is characterized by student sequencing through course material in a self-paced manner. ICW is defined as training material that uses a computer, videodisc, or other multi-media device, as the primary basis of instruction. Our main goals in developing the GCBT system are to:

- Shorten the courseware development time through reusable code: By employing the object-oriented programming methodology, the source code for the CBT courseware can be organized into a hierarchy of classes and subclasses (objects). From this library of objects, new courseware can be easily developed by reusing existing objects. This is the inheritance property of object-oriented programming methodology.

- Produce portable courseware: GCBT runs on DOS Windows 3.0[1] and OS/2 Presentation Manager and it employs ToolBook OpenScript[2] [3] as the authoring language. Also, since IBM is a member of the Interactive Multimedia Association (IMA), the GCBT system has adopted the IMA's Practices for Multimedia Portability [4] which is also known as MIL-STD-1379D Appendix D (for portable courseware).

- Effectively deliver and monitor the training objectives: In GCBT, each courseware is developed with its training objectives, and its student performance data are stored in the database which can be used for statistical analysis.

SYSTEM ARCHITECTURE

Through product development, industry-wide authoring software evaluation studies, and program experience, IBM Manassas developed an authoring environment architecture--the GCBT system--shown in Figure 1 that integrates Commercial-Off-the-Shelf software and hardware products. This architecture optimizes the functionality of each software product, increases the user's productivity by providing seamless integration, and provides modularity to allow the most flexibility for growth.

The GCBT system architecture and local area network (LAN) topology is shown in Figure 1 (part A). The GCBT system can be configured as a stand-alone LAN without the Host connection. The GCBT architecture consists of 21 workstations: 17 Student, 3 Development, and 1 File Server/Print Spooler. The Development workstation provides the ICW development capabilities, the courseware is delivered at the Student workstation, and the File Server/Print Spooler provides file server services, printer services for the LAN, and acts as the Host gateway.

Both Student and Development workstations are configured with similar hardware capabilities. This provides development functions for the Student workstations when not in use by the students, and delivery functions for the Development workstations when not in use by the ICW developers. The Development workstation represents an advanced version of the Student workstation; however, the Student workstation does not have the video capture and scanning capabilities.

The Student and Development workstations use the same PS/2 model to assure the courseware developed and tested on a Development workstation will not incur performance degradation when run on the Student workstation. The hardware configuration for the

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[1] Windows 3.0 is a registered trademark of Microsoft Corp.

[2] ToolBook OpenScript is a registered trademark of Asymetrix Corp.

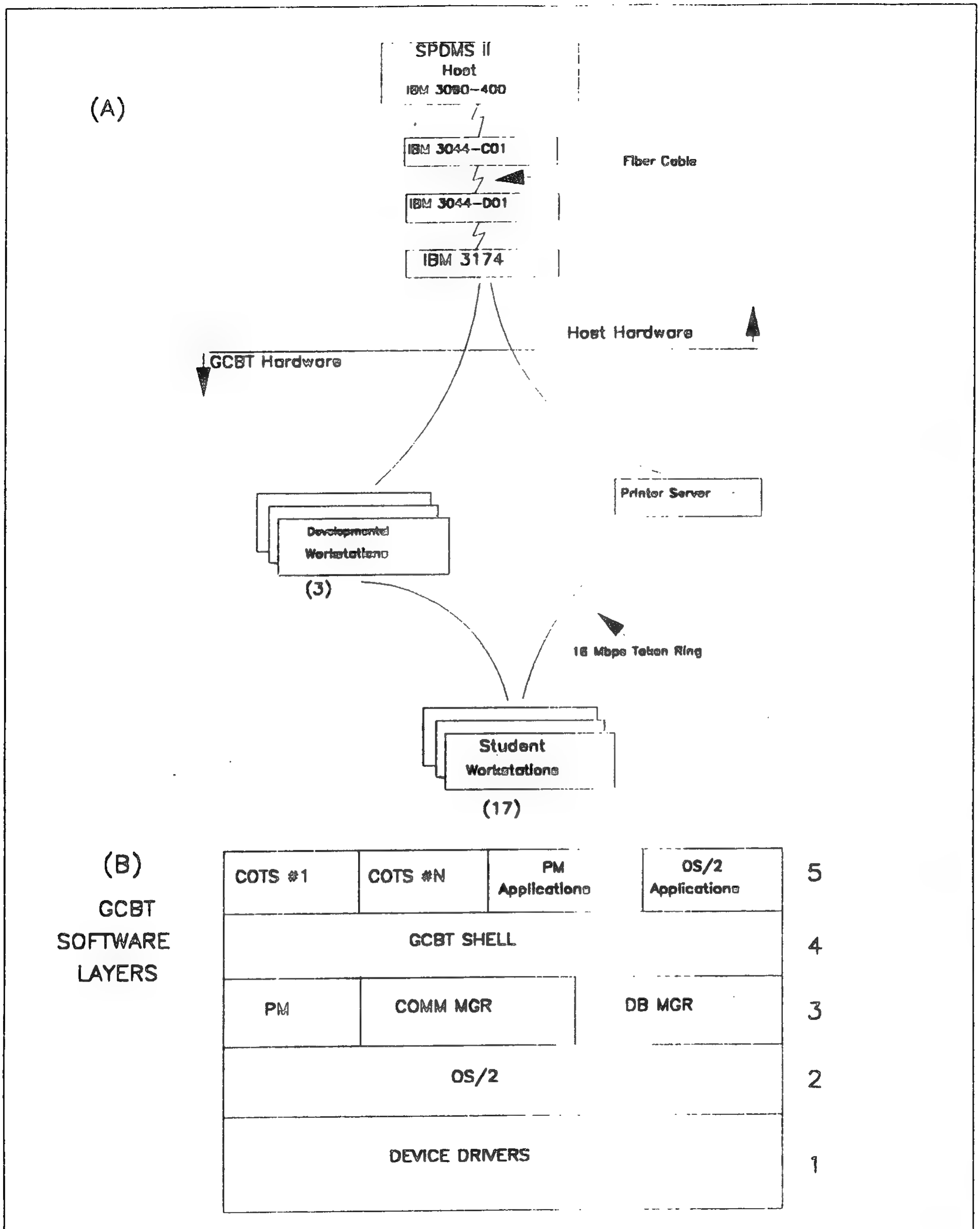

Figure 1. GCBT System Architecture and Software Architecture

workstations provide support for digitized audio, digitized video, full motion video, and graphics. The PS/2 was selected because of overall Micro Channel bus performance, operating system performance of OS/2 Extended Edition, and the exclusive video bus. The video bus is important for merging VGA text and graphics with full motion video received from the current M-motion adapter or future DVI[3] (Digital Video Interactive) products.

Full motion video capability is provided using IBM's M-motion adapter. Up to three NTSC or two Super VHS video sources can be controlled by the adapter. M-motion also allows for integration of computer graphics with video/text overlay onto the video images. The Video Capture adapter (VCA) provides digitizing, editing, and storing of compressed video images. The Audio Capture and Playback adapter (ACPA) provides high fidelity audio with a sampling rate of 44.1 KHz. The ACPA card can capture, digitize, store, and playback dynamic length audio segments. A SCSI adapter is used to attach the Erasable/Rewritable Optical Disk (EROD) and tape backup unit. The EROD is a means to store large amounts of data (for example, courseware material) on removable media. All workstations will be connected via a Token Ring LAN. The network will be running at 16 megabits per second. The File server will house eight printers and contain the database and the libraries.

SOFTWARE ARCHITECTURE

In this section, we will first briefly introduce the concepts of concurrent object-oriented programming, then present the software architecture of the GCBT system. Finally, we will describe the COOP implementations in the GCBT system.

COOP CONCEPTS: Objects can be defined as entities that encapsulate data and operations into a single computational unit. Concurrent object-oriented programming is a programming and design methodology in which the system to be constructed is modeled as a collection of concurrently executable modules (objects), that interact with one another by sending messages. COOP combines the object-based notion of encapsulation, classes, and inheritance with the concurrent concepts of threads, synchronization, and communication [1,7].

A common semantic approach to modeling objects is to view the behavior of objects as functions of incoming communications. This is the approach taken by in the actor model [2]. Actors are self-contained, interactive, and independent components of a computing system that communicates by asynchronous message passing.

The GCBT system implements a modified version of the Hewitt-Agha

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[3] DVI is a registered trademark of Intel Corp.

actor-based model for COOP. By using the COOP in the GCBT system, we achieved modularity and code (courseware) reusability, which are inherently the byproducts of COOP.

GCBT SOFTWARE ARCHITECTURE: The software in the GCBT system is composed of five layers as shown in Figure 1 (part B). Layer 1 contains the device drivers which control all underlying hardware devices such as the laserdisc player and the ACPA card. The device drivers provide a set of Application Programming Interfaces (APIs) that the user can use to request device services [14]. Since IBM is a member of the IMA, the GCBT system has adopted the IMA's Recommended Practices for Multimedia Portability (version 1.1) which can be implemented in the device drivers. Thus, the GCBT system is compliant with the MIL-STD-1379D Appendix D for portable courseware.

Layer 2 is the multi-tasking operating system OS/2 [8,11] which provides system services such as memory management, process/thread management, and resource management.

Layer 3 adds more capabilities to the basic operating system services in OS/2. Layer 3 has three main components:

- Presentation Manager (PM) is an object-oriented tool [5,10] that provides the Graphical User Interface (GUI) with windowing capabilities. PM standardizes a common user access (CUA) for all applications operating in the OS/2 environment [9].

- Communication Manager [13] provides the connectivity, concurrency, terminal emulation, programming interfaces, and communications services for applications operating in the OS/2 environment. Communication Manager supports the IBM Token Ring (IEEE 802.5 & 802.2) and Ethernet (IEEE 802.3) adapters, from which the software can be written in NETBIOS or TCP/IP protocols.

- Database Manager [12] is based on the relational database model. The Database Manager provides database services through the Structured Query Language (SQL) which is used to define, query, and update the database in stand-alone or networking mode.

Each component in layer 3 provides the software interfaces through a set of standardized APIs.

Layer 4 is the GCBT Shell which provides a generic form for communication between the applications in layer 5 (for example, COTS products), and for communication from the non-COTS applications in layer 5 to other layers (for example, Database Manager) in the GCBT system. The GCBT Shell provides a structured method of cooperation and communication between applications by employing the OS/2 inter-process communication (IPC) facilities such as semaphores, signals, queues, pipes, and

dynamic data exchange (DDE) [6,8]. The GCBT Shell standardizes the IPC process by providing dynamic link libraries (DLLs) that the COTS product can use to communicate and coordinate with other applications. The GCBT Shell also provides a seamless user interface across the COTS products to make GCBT look and feel like a single product.

Layer 5 contains the COTS products such as:

- ToolBook [3]
- WordPerfect[4]
- MKS Revision Control System (RCS)[5]
- Image Support[6]
- Audio/Visual Connection (AVC)[7]
- Corel Draw[8]
- EasyFlow[9]

Layer 5 also contains other PM applications, not COTS products, such as Computer-Managed Instruction (CMI), Video Server, and Audio Server.

ToolBook is an object-oriented tool. Each object in ToolBook contains data and operations that are written in the ToolBook OpenScript language. The user can easily use ToolBook to create objects from which ToolBook can automatically generate the script for those objects. To ease the task of ICW development, the GCBT system supplies a hierarchy of classes and subclasses of CBT objects such as playback_full_motion_video, playback_audio, bookmarking, pose_question, record_answers, and display_graphics. From this library of objects, new courseware can be easily developed by using these existing objects. The reusability is the inheritance property of object-oriented programming.

COOP IMPLEMENTATIONS: The GCBT system is an actor-based system. For example, if a courseware needs a full motion video playback segment, the ICW author copies the "playback_full_motion_video" object from the library into his script. All the author has to add are the from and to frame numbers. At run time, that object will send a message, which is a Recommended Practices [4] command such as "vdPlay from=100 to=800," to the Video Server (actor)

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[4]WordPerfect is a registered trademark of WordPerfect Corp.

[5]MKS RCS is a registered trademark of MKS Corp.

[6]Image Support is a registered trademark of IBM Corp.

[7]AVC is a registered trademark of IBM Corp.

[8]Corel Draw is a registered trademark of Corel Systems Corp.

[9]EasyFlow is a registered trademark of Haven Tree Software Corp.

which will playback the full motion video segment accordingly. This modular design insulates the courseware from hardware changes (such as the laserdisc player) and thus ensures portable courseware. Furthermore, since ToolBook also offers the runtime software for DOS/Windows 3.0, courseware that is developed on the GCBT system will also run on Windows without any modifications, that is, it will be portable across different platforms.

The GCBT system employs the MKS RCS product for revision control of the courseware. However, the GCBT Shell provides the courseware configuration management (CCM). The GCBT system maintains two sets of tags--Properties and Attributes--for each object. The Properties tag is created and maintained by MKS RCS. It contains the change and can include its name, a text abstract, the author, associated source code, object code, and binary images. The Attributes tag is created and maintained by the GCBT Shell and it contains the EROD number, video disc number, course number, release number, operating system name, and hardware platform name. At the high level, each course is an object that contains a group of objects configured by the ICW author. In this way, courseware configuration for new releases is easily managed.

OPERATIONAL CAPABILITIES

The GCBT system provides the ICW developer with an assortment of features to produce Level III Interactive lessons incorporating digital audio and video, and provisions for future digital motion video applications. The GCBT system also provides extensive capabilities for student tracking and evaluation. Level III Interactive is defined as follows: the Level III interactive videodisc applications must allow for full integration of computer-generated text videodisc information to generate message-conveying techniques (such as, voice explanation over computer text or graphics, or animated computer graphics mixed with videodisc images). Specialized presentation components (such as, digital audio and video) must be fully integrated into the presentation system. The GCBT courseware can be delivered in team-training mode or in individual-training mode on either OS/2 or DOS/Windows platforms.

GCBT is a database-driven system. All student, developer, and administrator information is stored in the OS/2 database. The database includes information on rostering, courses, lessons, questions, answers, objectives, and tasks. DLLs were written to provide access to the database for applications such as ToolBook. From the authoring environment, questions and answers are downloaded from the database. When the student exits the lesson, student responses and other information (such as bookmark) is stored in the database. The GCBT Shell invokes calls to the database to verify user access to the different functions, list courses and lessons for the students, and maintain the database for the administrator.

There are three main functions in the GCBT system: Delivery, Development, and Administration. Each function can be accessed via any workstation on the LAN and is password protected to prevent unauthorized access. For example, students do not have access to the Development and Administration functions. To log on, the user is required to enter a userid and password. The user also has the option of changing the password on this screen. After the student is successfully logged on, a course catalog is displayed. This is a selectable list of courses the student is required to complete. Each course has a list of associated lessons that is presented after the student selects the course. The lessons are separated into three categories: Recommended Lessons, In-Progress Lessons, and Completed Lessons. Upon selecting a lesson, an information screen is displayed and the lesson is started.

The Development function provides tools to facilitate in the development of lessons (courseware). After the developer successfully logs onto the system, the development tools screen is displayed. This is a list of COTS products which can be used to aid in the creation of the lessons. These tools can be replaced by any COTS product. The selectable tools are: Authoring, Word Processing, Database Management, Tape Backup, Flow Charting, Graphics, Revision Control, Scanning, Full Motion Video, Video Capture, and Audio.

The authoring tool being used is the OS/2 version of Toolbook. DLLs were written to support the integration of full motion video, database support, digitized audio and images into Toolbook. Commands issued from Toolbook will invoke these different functions, thus making the integration of the lesson (courseware) seamless.

The Administration function provides tools to facilitate in the management of the database and the GCBT system. After the administrator successfully logs onto the system, the administrator tools screen is displayed. The tools include: Word Processing, Computer Management Instruction (CMI), Tape Backup, and Configuration Management. These tools can be replaced with other COTS products.

The CMI provides standardized interfaces to the database so that the GCBT system can be tailored to specific training requirements. The user is still able to enter OS/2 Query Manager and create reports, update tables, and create queries. However, data input and deletion can be done using the CMI interface. This includes functions to add courses, add users, change passwords, delete questions, or list lessons as examples. These functions were created to also help maintain data integrity.

The CMI capability provides the user with student administration, test, student reporting, and tracking of individual student progress through course of instruction (for example, test scores and bookmark). The student administration involves student

sign-on, student lesson assignment, and archiving student data. Students are evaluated using tests consisting of true/false, multiple choice, fill-in, and matching questions. The system will record the responses to all questions asked to the students. Each student will be presented with a unique set of questions. This may be a re-sequencing of the questions or new questions. Student reports provide information to the instructor regarding the student's progress and completion of the training. These reports are accessible by the instructor and the student.

The GCBT system supports the Instructional Systems Development (ISD) process. Using the Database Manager, collection forms are created to aid in the gathering of task-specific information from subject matter experts and field observation. Upon entering the task data into the database, the course developer queries the database to analyze tasks common to more than one job skill and to compare target population data against task performance requirements. Based on this task analysis, the course developer decides which tasks are used for training. The course developer then develops a set of behavioral objectives specifying the subtasks, skills, and knowledges for each task in the training program. The objectives are presented in a hierarchical format to ensure proper sequencing of training to produce the most learning in the shortest period of time.

Using the products supplied in the GCBT system--word processing, flow-charting, and database manager--the course developer prepares the flow diagrams, scripts/storyboards, ICW evaluation items, production requirements, and the training facilitator's guide for each lesson.

SUMMARY

The GCBT system is composed of a user interface (the GCBT Shell) and COTS software. The user interface provides a seamless environment containing the COTS products. This approach allows for replacement of the COTS products without any programming effort. The COTS products were selected to provide the different aspects of authoring ICW, such as, editor, graphics, authoring language, scanner support, flow chart, full motion video, and digitized audio. In this way, the GCBT system can be easily configured to satisfy current and future customers' CBT requirements. The GCBT courseware can be delivered in team-training mode or in individual-training mode on either OS/2 or DOS/Windows platforms.

By using the COOP methodology in the GCBT system, we achieved modularity and code (courseware) reusability, which are inherently the byproducts of COOP.

The GCBT system was selected by the Lockheed Space Operations Company (LSOC), over other commercial-off-the-shelf CBT systems, to satisfy their CBT requirements. Currently, LSOC is planning to use the GCBT system, in their mission with the National

Aeronautics and Space Administration to provide more cost effective, timely, and efficient training tools for the Space Shuttle Launch Team.

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BIOGRAPHICAL SKETCH

Quang M. Tran received a B.S. degree in Computer Science from the University of South Dakota in 1974, and a M.A. degree in Mathematics in 1977 from Wesleyan University. Mr. Tran joined the IBM Corporation in New York in 1978. Since then, he has worked on several large software development projects at IBM, most notably the MVS/XA operating system, the 21B64C sonar operator trainer, and the AN/BQQ5-D sonar. Currently, he is an advisory software engineer in the Training Systems organization at IBM Manassas and is the principal architect in the GCBT project. He is a member of the Association for Computing Machinery and the IEEE Computer Society.

Jean M. Crowley received a B.S. degree in Computer Science from Virginia Polytechnic Institute and State University in 1987. Ms. Crowley joined IBM in Manassas, Virginia, in 1987. Since then, she has worked on several independent research and development systems for use in future training and classroom models. Currently, she is a senior associate software engineer in the Training Systems organization at IBM Manassas and is the lead designer for the CBT LTTS system.

Visual Simulation Technology for Part Task Trainers

Bruce Montag
Southwest Research Institute

Introduction

This paper presents an overview of visual simulation techniques that have been applied for space shuttle part task training. These techniques are also directly applicable to the development of part task trainers for airborne weapons systems. Specific techniques covered include virtual 3D displays and controls, camera/sensor scene simulation, and functional simulation of operational flight programs (OFPs).

A visual simulation based part task trainer was recently developed for the NASA Johnson Space Center under a manned spaceflight simulation research program. The Rendezvous Radar Trainer is a workstation based part task trainer that is designed for instructing pilot-pool level astronauts in the operation of the Ku-band rendezvous radar system on board the space shuttle. The rendezvous radar system features both manual and operational flight program control of the radar mechanical assemblies and electronics, man-in-the-loop control through hand-eye coordination and tracking, multiple concurrent display output devices, and crew-flight program interfacing through keypads and CRT's.

This paper provides a detailed discussion of the trainers design, including how visual simulation was used to satisfy part task training objectives. The trainer provides full control over simulated payload bay cameras, allowing the student to visually inspect the radar assembly, the payload bay doors, and individual payloads. This visual capability aids in student understanding of system operations. In addition, students are able to correlate instrument readings with physical equipment conditions as seen through the camera. Development cost for the rendezvous radar trainer was minimized through the use of a functional simulation approach that focused on tailoring the software architecture to support specific training objectives. Suggestions for extending the visual part task trainer approach to cover airborne weapon system applications in the areas of sensor simulation, weather visualization, and terrain rendering are then presented for discussion.

Visual Simulation Alternatives for Part Task Training

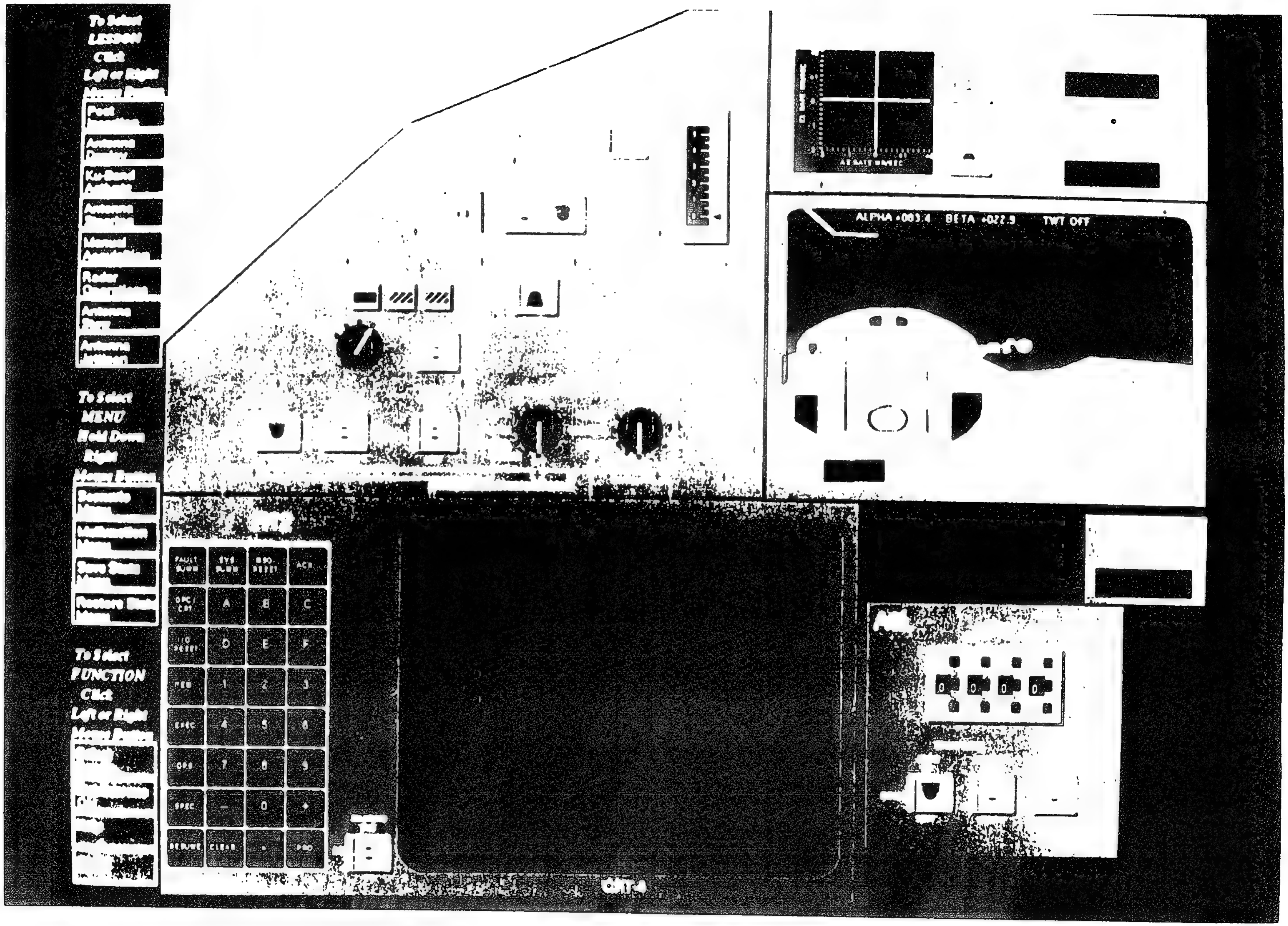
As full up operational flight trainers (OFTs) have become more complex to accommodate mission rehearsal demands, many end users have become increasingly more interested in low cost man-in-the-loop simulation alternatives for part task training. Part task trainers can provide a cost effective alternative to OFTs for providing crew members with hands-on training in a variety of mission critical, time dependent tasks. Currently, four methodologies are available for implementing visual simulation functions within part task trainers. These are: 1) hardware stimulation, 2) hardware emulation, 3) architecture emulation, and 4) functional simulation.

Hardware Stimulation

Under the hardware stimulation approach, visual simulation functions are provided through the use of operational mission equipment within the part task trainer design. An example would be the incorporation of an aircraft digital image tracker whereby the tracker is stimulated with computer generated imagery and control signals from the PTT host computer. This approach has the advantage of increased validity in terms of trainer performance, but has disadvantages in the areas of development cost, and reliability/maintainability.

Hardware Emulation

With the hardware emulation approach, the visual simulation functions are emulated within the PTT through the use of commercial hardware that is functionally equivalent to the mission equipment. An example of this approach would be the use of a commercial-off-the-shelf image processor in place of the aircraft digital image tracker within the PTT. This method results in improved reliability, but still results in a complex, expensive design approach. In addition, maintaining concurrency with the aircraft may be difficult due to either peculiarities of the image processor or unique techniques that may be required to implement aircraft changes.



Rendezvous Radar Trainer

Architecture Emulation

An approach aimed towards improving concurrency between the PTT and the operational equipment is to emulate the architecture of the operational equipment within the PTT design. Under this approach, each component of the applicable mission equipment is emulated within the PTT in terms of function and interfaces. This method, typically used for flight simulator design, improves on the ability to track configuration changes, but results in a cumbersome PTT design that emphasizes configuration validity over training effectiveness.

Functional Simulation

A fourth approach is to deemphasize the operational equipment configuration and simulate only those functions that are required to support part task training objectives. This is the approach that was taken for the NASA rendezvous radar trainer. Since the PTT design is based on functional performance, the PTT is only impacted by those operational equipment changes that result in performance differences that are visible to the crew.

A software intensive approach, functional simulation provides a means for designing PTT's that are low cost, focus on end user requirements, are easy to update, and may be tailored and reused for similar type mission equipment training.

With the functional simulation approach, PTT training objectives are defined in light of the operational system capabilities for the mission equipment, and PTT software requirements are then derived from the training objectives. This structure provides for requirements traceability and provides a direct means for correlating development cost with training objective.

Functional Simulation Applied

The SwRI developed rendezvous radar trainer was designed for NASA using a number of visual simulation techniques that are extensible to airborne weapons training. The following presents an overview of the functional simulation approach as applied to this trainer.

Operational System Description

The rendezvous radar trainer supports mission critical training objectives in the operation of the Ku band system on board the space shuttle. Figures A and B show the location and configuration of the Ku band antenna on board the shuttle. The Ku band system serves as both a rendezvous radar and as a communication link to the TDRS satellites. Crew members operate the rendezvous radar system from the aft flight deck of the shuttle as shown in Figure C. The rendezvous radar system features characteristics that are similar to many airborne weapons systems including operational flight program control, man-in-the-loop control and multiple interactive displays and controls.

Part Task Training Objectives

An example of training objective decomposition into tasks for the rendezvous radar is given in Figure D. For the objective "Operate Rendezvous Radar", five tasks have been identified, each task defined by a set of conditions, procedures, and standards for task performance. The conditions define the training situation in terms of displays and controls. Procedures describe how the student is expected to interact with the conditions, and the standard defines the criteria for successful task accomplishment.

Derived PTT Requirements

Once all training objectives and subsequent tasks were identified for the rendezvous radar, specific trainer requirements to support the training objectives were defined. It was mutually agreed upon that each task would be implemented as a selectable trainer lesson. When the student selected a lesson, they would be presented with all displays and controls necessary to perform the task (conditions), and their procedures would be automatically tracked to assess task performance (standard). In addition, initial condition sets were determined, instructor selectable malfunctions were defined, and trainer controls were selected.

Functional Design

The trainer was designed as a visual simulation application for execution on any Silicon Graphics workstation. It was desired that special hardware or software not be required to host the rendezvous radar trainer. This is one of the key strengths that visual simulation technology has to offer for part task

trainer development. In addition, it was desired that no programming knowledge or special instructions be required on the part of the student to operate the trainer.

Software requirements were grouped into two distinct areas: 1) user interface and 2) system simulation. This separation was designed to allow maximum flexibility in tailoring the trainer to meet future needs, such as incorporating actual equipment displays or additional simulation models. Through this approach, visual simulation techniques via virtual displays and controls can be effectively implemented to prototype or precede the use of mission equipment. Figure E illustrates the high level design of the rendezvous radar trainer, including allocation of the major software components.

Simulation Modeling Approach

The rendezvous radar trainer software includes four real-time simulation models: 1) Radar Model, 2) On Board Computer Model, 3) Rendezvous Model, and 4) CCTV Model. These models are time sliced and updated at a 15 Hz rate in response to student interactions. An executive program controls model execution and directs model to model communication through shared memory.

The Radar Model simulates the operating characteristics of the Ku band system, including mode control, signal processing, and antenna mechanical assembly dynamics. The On Board Computer Model simulates the operational flight program controlled functions pertaining to the radar, including keypad syntax, mode control, sensor integration, and malfunction logic. The Rendezvous Model simulates the flight trajectory of the shuttle and a rendezvous target in a typical shuttle orbit through a simple three body orbital mechanics algorithm. The CCTV Model renders visual scenes for any of the cameras located in the payload bay. Visual features modeled include the Ku band antenna mechanical assemblies, payload bay interior, and the payload bay doors.

Trainer Metrics

The rendezvous radar trainer was designed, implemented, and validated within a period of nine months by a team of three simulation engineers. The baseline trainer software configuration consists of 20,000 lines of new development source code written in the C language.

Extension to Airborne Weapons Training

Many of the visual simulation concepts utilized for the rendezvous radar trainer are high extensible to airborne weapons training. the virtual displays and controls, cooperating simulation models, and visual scene simulation techniques utilized for the rendezvous radar trainer may all be tailored and reused for application to airborne weapons training. Improved workstation based Ada development tools along with emerging standards in the areas of graphics libraries (GL, PEX) and POSIX compliant application program interfaces (API's) may now allow visual simulation models to be developed that are transportable and reusable across a wide range of workstation platforms and end user application areas.

Sensor Simulation

With the aide of these emerging standards, the functional simulation approach may be applied to develop training effective sensor simulation models for satisfying part task training objectives across a number of weapons systems. Visual simulation based software models developed via functional simulation offer many benefits in that development cost is low, they may be readily reused, and they only need to maintain concurrency with operational equipment performance, as opposed to equipment configuration. Examples of visual simulation based sensor models in support of man-in-the-loop part task training include radar warning receivers, multimode fire control radars, FLIR sensors, missile approach warning systems, and weapons seekers.

Tactics Analysis

Workstation based visual simulation applications may also be effectively used to analyze and evaluate tactical scenarios for both mission planning and post-action debriefing. SwRI is currently developing a workstation based tactics analysis tool for an Air Force sponsor that allows mission analysts to interactively view multi-aircraft scenarios.

Weather Visualization

Emerging visual simulation techniques in the areas of volume visualization and increasing workstation performance may now allow 3D weather effects to be simulated for part task training. One promising approach is to render visual weather scenes based on doppler radar or super computer based data sets that describe weather conditions within a specific

volume of airspace over a given period of time. SwRI is pursuing this approach for the visualization of microburst windshear conditions, but the technique may also be applicable for incorporating combat weather conditions into man-in-the-loop trainers.

Terrain Rendering

Workstation based part task trainers utilizing visual simulation technology are also well suited for accommodating emerging digital terrain data sources for visualizing ground environments. Powerful graphics architectures and multi-processor capabilities allow workstations to produce highly detailed terrain imagery based on emerging types of digital source data including Multispectral Imagery (MSI) and Tactical Terrain Data (TTD).

Summary

Visual simulation technology has advanced to the point where many training features that have traditionally been reserved for operational flight trainers are now available for incorporation in part task trainers. Virtual displays and controls, out the window scene generation, sensor simulation, and on board computer modeling may all be applied within man-in-the-loop oriented part task trainers. Through the use of the functional simulation development methodology as presented here, these features can be developed to maximize training effectiveness while minimizing trainer development cost. In addition, workstation based visual simulation capabilities are rapidly emerging that allow new training features such as weather simulation and new digital terrain data products to be accommodated for part task training.

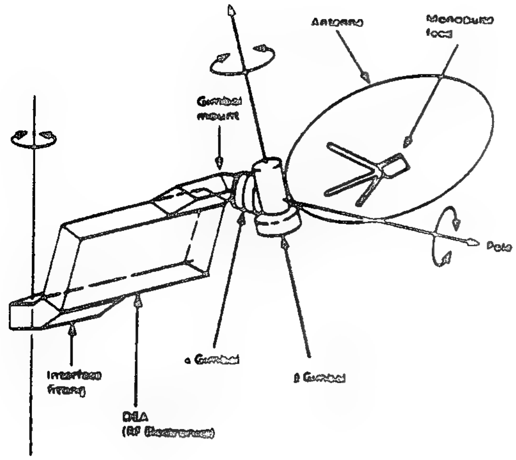


Figure A - Ku Band Assembly

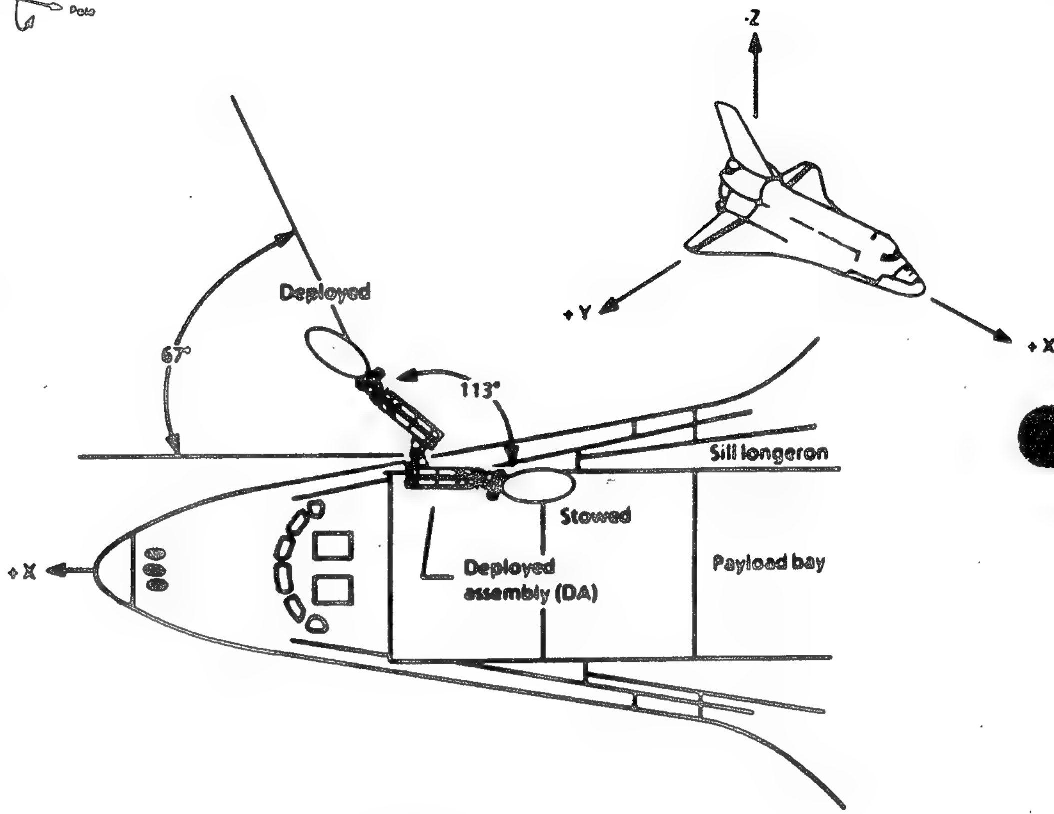


Figure B - Ku Band Location

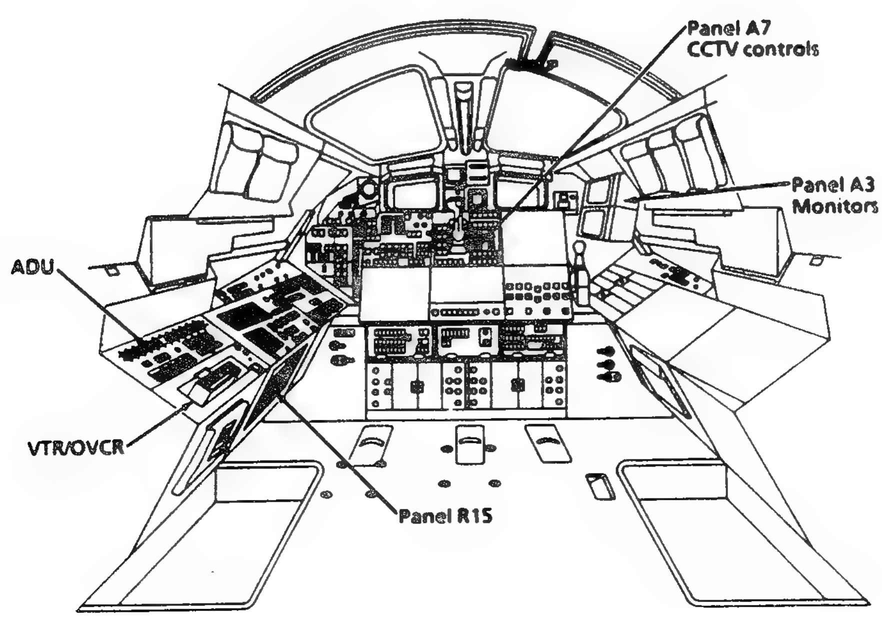


Figure C - Shuttle Aft Flight Deck

OBJECTIVE #2: Operate Rendezvous Radar			
TASK	**CONDITIONS**	**PROCEDURES**	**STANDARD**
1) *Demonstrate GPC mode operation*	-Panel A1U -Panel A2 (multiple scenarios) · CRT (OPS 201) · Z window target viewing	Demonstrate features of GPC mode including auto search and track, coast through obscuration zone, auto reacquire after break, and angle wander when az/el > 30 deg.	All GPC mode features excersized
2) *Perform Radar navigation procedure*	-Panel A1U -Panel A2 -CRT (SPEC 33) · Z window target viewing	Track target and update navigation filter with radar data. Monitor and assess radar/nav data on CRT	Good radar data successfully transferred to NAV Propogated Data program
3) *Demonstrate GPC DESIG mode operation*	-Panel A1U -Panel A2 (multiple scenarios) -CRT (OPS 201) -Z window target viewing	Demonstrate GPC DESIG features including 2 second angle update, range search, and control loss when pointing through the obscuration zone	All GPC DESIG characteristics demonstrated to show why this mode is not used for prox ops
4) *Demonstrate AUTO/MAN mode operations*	-Panel A1U -Panel A2 (multiple scenarios) · CRT (OPS 201) · Z window target viewing	Demonstrate AUTO and MAN mode features including main/mini scan search, dual slew rates, manual beam centering, and break track logic	All AUTO/MAN characteristics demonstrated
5) *Demonstrate Proximity Operations Radar Control*	-Panel A2 -Panel A1U -CRT (OPS 201) -CCTV DA animation	Demonstrate close in radar control including scan warn logic, gimbal limits, and RF power management	Safe usage of the radar in proximity operations is demonstrated

Figure D - Example Training Objective Decomposition

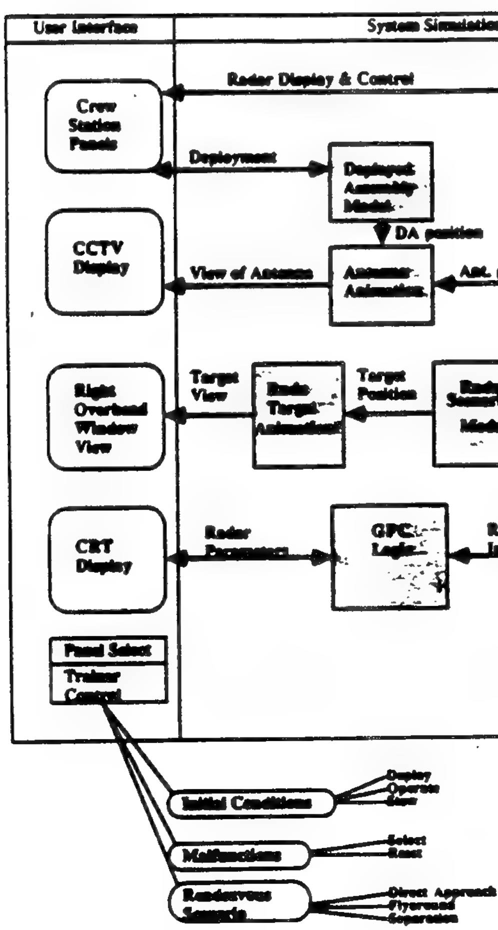


Figure E - Rendezvous Radar Trainer Approach

The Threat Matrix:
A Hypermedia Lesson That Teaches Facts About the Naval Forces of the World

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The Threat Matrix:
A Hypermedia Lesson That Teaches Facts
About the Naval Forces of the World

In 1988, Iowa State University's College of Education and Media Resources Center (Ames, Iowa), contracted with Oak Ridge Associated Universities, Inc. (Oak Ridge, Tennessee) to develop a plan to promote the increased use of educational technology by the instructors and students of the United States Navy's Surface Warfare Officers School (SWOS). Located in Newport, Rhode Island, the mission of SWOS is to:

- provide the Naval Surface Warfare Force, through a system of functional training, with officers professionally qualified to serve as effective naval leaders on surface warfare ships with the ultimate goal of Command-at-Sea.

- serve as a focal point for development and integration of qualification standards and functional training in support of the established continuum of Surface Warfare Officer professional and billet specialty training.

One of the curriculum areas at SWOS is designed to prepare officers to work in a ship's "Combat Information Center" (CIC), where they have the responsibility of interpreting information collected from electronic sensors and human look-outs. When a "contact" is made by the ship's radar, or from a surveillance plane, it is the responsibility of this officer to determine what the "contact" is, and to determine its threat.

One of the basic skills needed by a CIC officer is the ability to recall the names and characteristics of the warships and aircraft of the fleets of the nations of the world. Initially, this information is memorized, and SWOS students are tested on their ability to remember this data. Later, students apply their factual knowledge to realistic simulations of threat situations.

To facilitate learning, SWOS instructors and students organize the "threat" information into a chart with columns (ships) and rows (characteristics) and they refer to it as the "threat-matrix" (TM). The TM, as it is presented by SWOS instructors, contains thousands of facts that students must memorize, including:

- colored pictures, usually slides, of ships, aircraft and weapons (e.g. missiles),
- line drawings of ships, aircraft and weapons,

- names of ships, aircraft and weapons,
- characteristics of ships, aircraft and weapons (e.g. speed, weight, electronic characteristics),
- relationships between other categories of information.

Once the data in the TM are memorized, students apply their knowledge in instructional simulations that evaluate their ability to function in a ship's CIC.

One important characteristic of the TM is the considerable overlap of the information contained in it. Ships and aircraft share weapons systems and sensors, and weapons carried by aircraft and ships have characteristics such as speed and range, as do the platforms themselves. Part of the difficulty involved in memorizing the facts of the TM is relating, or linking, facts to the various platforms where they are found. Officers traditionally memorize the information of the TM using flash cards, peer teaching groups, individual memorization, and other non-technological means.

The Hypermedia Lesson

Hypermedia is a relatively new term that is often defined as the use of computer-based systems to present a variety of media in a non-linear, randomly accessible manner. Hypermedia is often confused with multimedia which is similar but considered by most to be a subcategory of hypermedia. The linking capabilities of hypermedia environments permit learners to control their accessing of information, and to learn in a manner that is individual and unique for them, rather than in a predetermined, instructor planned way. There is even some research to support the contention that within certain parameters learners will select the best technique for their personal styles of learning. Since hypermedia systems with their linking and branching capabilities mirror the organization of the content of the threat matrix, and since naval officers learn the TM using a variety of techniques, it was decided that a hypermedia lesson would make an excellent tool for teaching and learning about the TM, and would ultimately become a rich environment in which to study how naval officers learn the TM.

In 1991, a prototype hypermedia lesson called "The Threat Matrix: A Computer Based Lesson (TM LESSON)" was developed. Later in 1991, the lesson's name was changed to the "Shipboard Systems Matrix: A Computer Based Lesson. The prototype lesson had the following characteristics:

1. It was constructed as a "shell" lesson that could be easily updated and changed. Specifically, the outline of the lesson was constructed by ISU instructional developers. The factual information inserted into this outline was obtained from the unclassified book, Combat Fleets of the World. The lesson was constructed so that SWOS officers could easily replace unclassified data, such as the speed of the Soviet warship KIEV, with classified information. IBM's recently introduced software package LINKWAY was selected as the authoring system for the lesson. LINKWAY is similar to Apple's Hypercard. Both software packages are inexpensive, require no modification to hardware, are widely available, and are considered excellent examples of hypermedia authoring systems.

2. It was MS-DOS based. Since the designated computer of the US Navy at that time was the Zenith model 248, it was the computer used to design the lesson. The lesson, with few exceptions, was developed to be "transportable" to any MS-DOS computer, including computers using 80386 central processors.

3. It was designed to be intuitive and easy to use. The metaphor of a "book" was identified as the theme for the organization of the lesson. In other words, the lesson had a cover, a preface, a table of contents, chapters, self testing sections, and an index. The book analogy was selected because Combat Fleets of the World was a reference Navy officers were familiar with and used to help them learn about the TM. This made the organization of the lesson straightforward which made it more likely that students would concentrate on learning the TM, rather than on how to use the computer lesson. Additionally, the lesson was graphically oriented and "mouse-driven." All commands were activated by pointing the mouse at a portion of the screen and clicking one button. The computer keyboard was almost never needed. Finally, a standard screen layout was selected for all of the lesson's pages. Identification information was always placed in the upper left corner of the screen, navigation information for movement through the lesson was always placed in the upper right portion of the screen, and TM visuals and data were always placed in the center and bottom two thirds of each screen. In other words, the lesson was designed so students would quickly become familiar with its organization. The intent was to make the delivery system "transparent," so attention could be placed on the information of the threat matrix.

4. It included various types of visual information which were used as mnemonics to help students remember facts. Line drawings of ships, aircraft, weapons, and sensors were included and were presented on the computer's screen. Additionally, the system included a videodisk player connected to and controlled by the computer. It played a videodisk containing thousands of still

and motion pictures which were displayed on a television monitor. The linking capabilities of LINKWAY were used to tie the visual segments of the lesson together.

5. It included self-test questions so that students using the lesson could evaluate their learning. Specifically, three kinds of quizzes were developed. There was a factual recall, multiple choice quiz. There was a line drawing identification quiz, and a still or motion picture recognition quiz.

Formative Evaluation

The prototype lesson was completed in early 1991, and delivered ready to use to SWOS by ISU instructional developers. Immediately, a SWOS instructor updated the lesson with the appropriate classified facts of the TM. The instructor was given approximately two hours of in-service in the operation of LINKWAY and the use of the lesson. Because of the way in which the lesson was created it was relatively simple for the SWOS instructor to modify with classified data the unclassified version of the lesson created by ISU instructional developers.

Next, the lesson was made available to SWOS students enrolled in the Department Head School's CIC curriculum. They were not required to use the lesson. Rather, it was an option for learning the TM that was made available to them. During the period of the course and following its completion, evaluation data were collected. In all cases the data were positive. Two comments were prevalent. First, students wanted a complete version of the lesson, and second, students asked for more copies of the system so several of them could learn simultaneously. Additionally, input from SWOS instructors were solicited. Their comments concentrated almost exclusively on the content of the lesson, not on its organization or delivery.

Because of the positive reactions of students and instructors, it was decided that the lesson should be completed and formally evaluated. Currently, ISU instructional developers are working closely with SWOS instructors to update and complete the lesson, now called the "Shipboard Systems Matrix (SSM)." The SSM will be completed by early summer, 1992.

Enclosures:

#1 The Threat Matrix Book

#2 Section: USSR

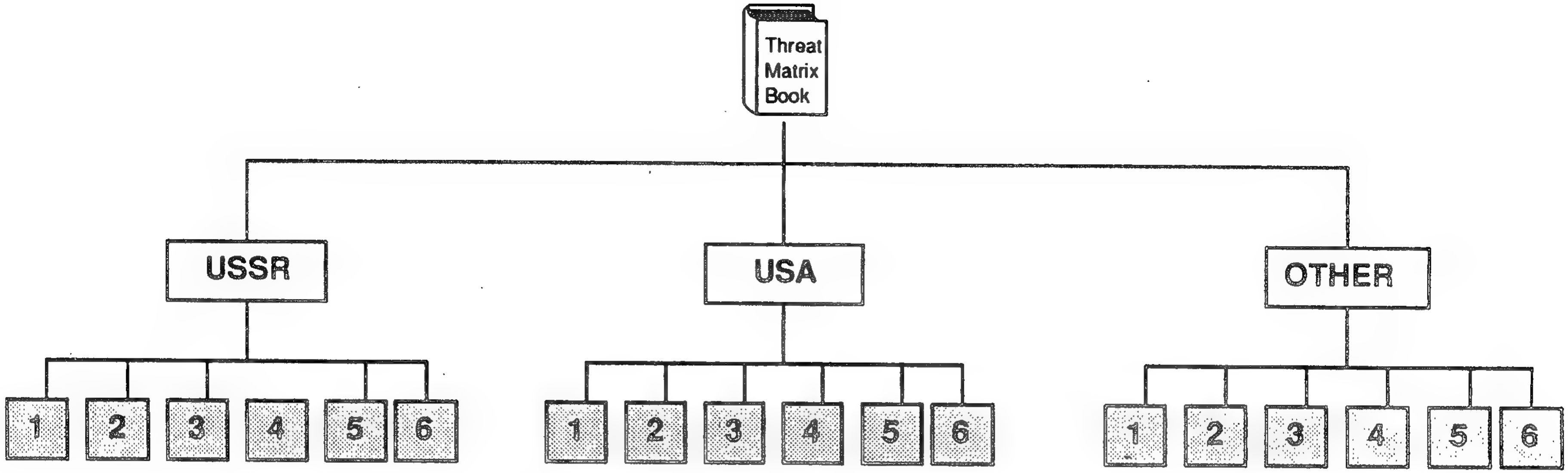
#3 Chapter 1: Surface Warships

#4 Chapter 5: Sensors

#5 Chapter 6: Weapons Systems

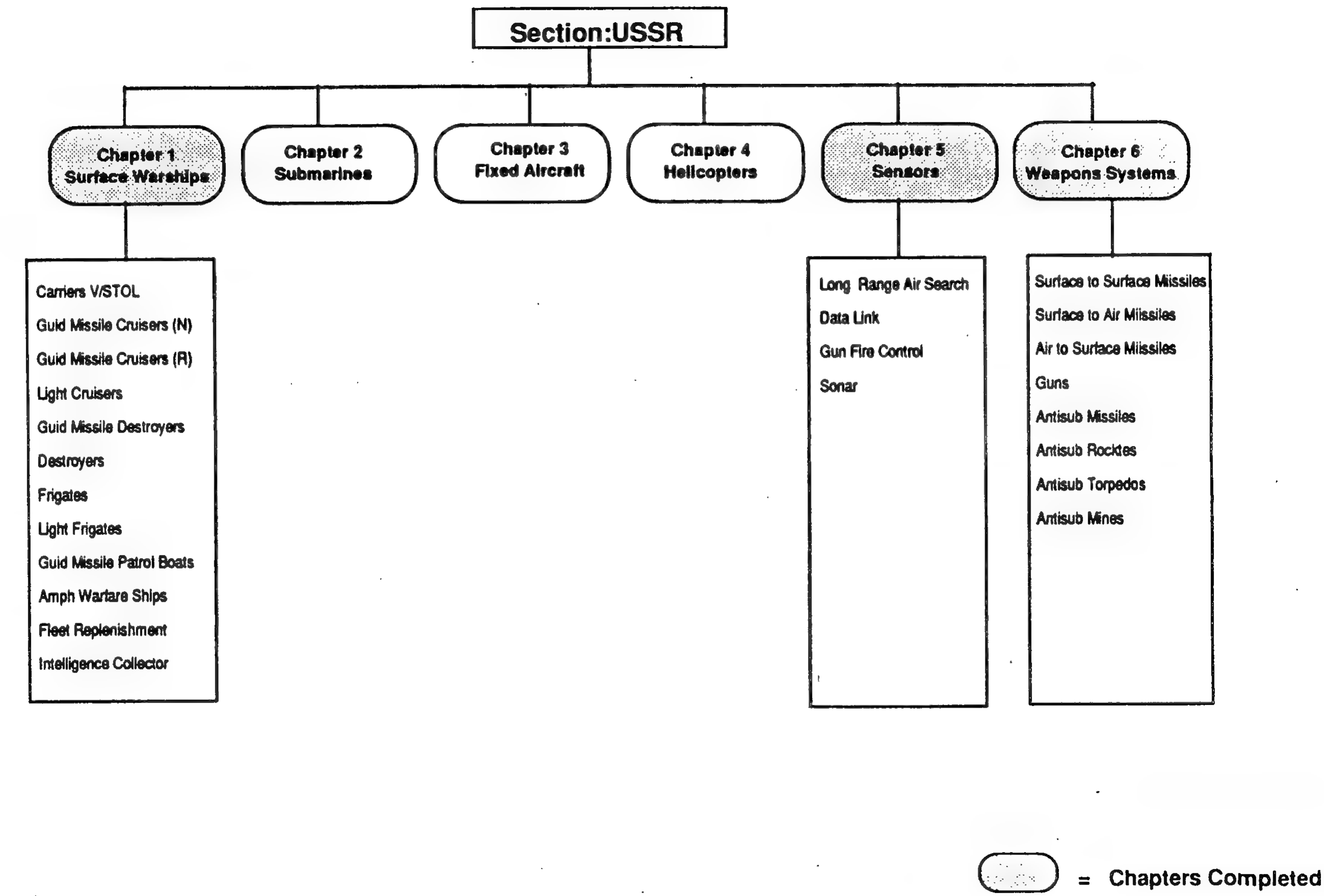
#6 Sample Quiz Item: Drawings

#7 Sample Quiz Item: Video Recognition



The Threat Matrix

- sections for USSR, USA, and Other countries
- six chapters for each section, containing:
  - Surface Warships
  - Submarines
  - Fixed Aircraft
  - Helicopters
  - Sensors
  - Weapons Systems

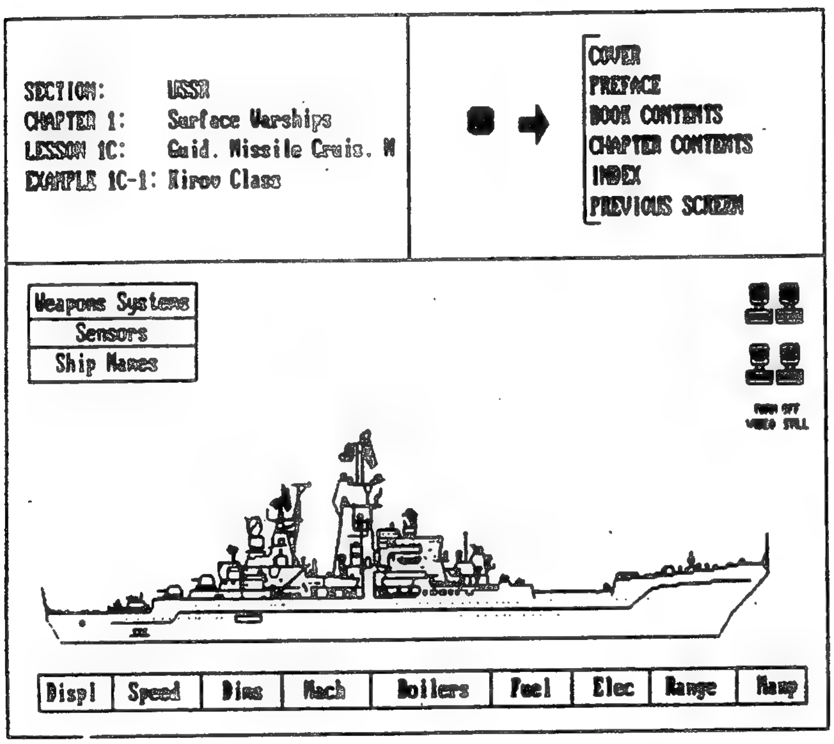

Section:USSR
Chapter 1
Surface Warships
Chapter 2
Submarines
Chapter 3
Fixed Aircraft
Chapter 4
Helicopters
Chapter 5
Sensors
Chapter 6
Weapons Systems
Carriers V/STOL
Guid Missile Cruisers (N)
Guid Missile Cruisers (R)
Light Cruisers
Guid Missile Destroyers
Destroyers
Frigates
Light Frigates
Guid Missile Patrol Boats
Amph Warfare Ships
Fleet Replenishment
Intelligence Collector
Long Range Air Search
Data Link
Gun Fire Control
Sonar
Surface to Surface Missiles
Surface to Air Missiles
Air to Surface Missiles
Guns
Antisub Missiles
Antisub Rocktes
Antisub Torpedos
Antisub Mines
= Chapters Completed

Chapter 1, "Surface Warships"
Example page from lesson

Cognitive Map
This section shows exactly where users are in the lessson. It also shows the user how this lesson example fits into the total "Threat Matrix."

Navigation Buttons
Clicking on the first five buttons will take you to that identified section. Clicking on "PREVIOUS SCREEN" will allow the user to retrace you moves, and see up to 12 previous screens.

Line Drawing
If available for this example, a scanned line drawing will be shown.



Video Buttons
If a green video icon is shown, clicking on it will show a motion video sequence from the videodisc. A red icon will show a still frame.

"TURN OFF VIDEO STILL" gives the user control of how long the video still image is on the screen

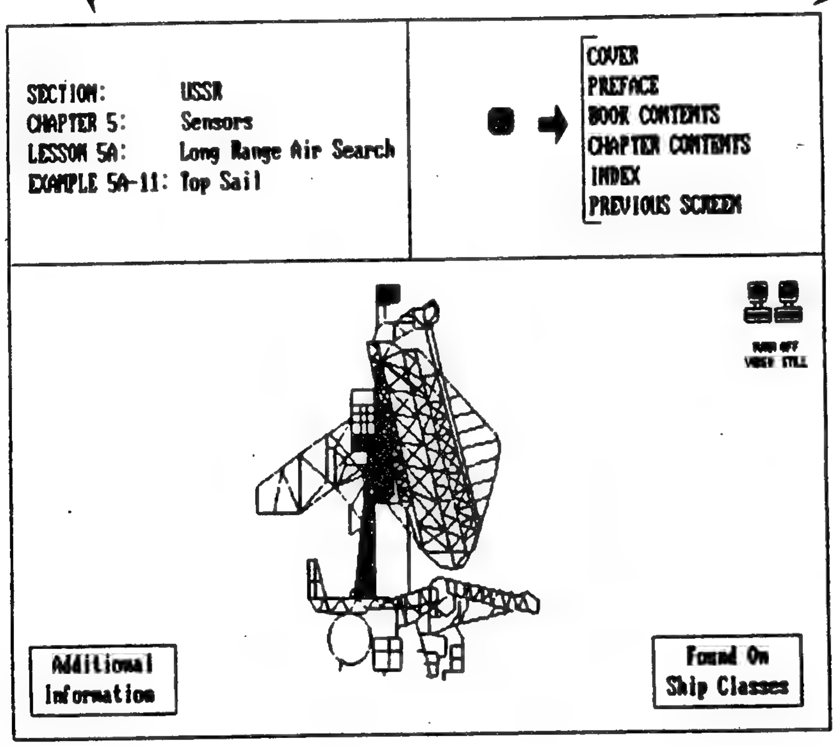
Information Pop-up Buttons
Click on any of these buttons to read more about its contents. When finished reading, click on the upper left corner of the pop-up box, and it will go away.

Chapter 5, "Sensors"
Example page from lesson

Cognitive Map
This section shows exactly where users are in the lessson. It also shows the user how this lesson example fits into the total "Threat Matrix."

Navigation Buttons
Clicking on the first five buttons will take you to that identified section. Clicking on "PREVIOUS SCREEN" will allow the user to retrace you moves, and see up to 12 previous screens.

Line Drawing
If available for this example, a scanned line drawing will be shown.



Video Buttons
If a green video icon is shown, clicking on it will show a motion video sequence from the videodisc. A red icon will show a still frame.

"TURN OFF VIDEO STILL" gives the user control of how long the video still image is on the screen

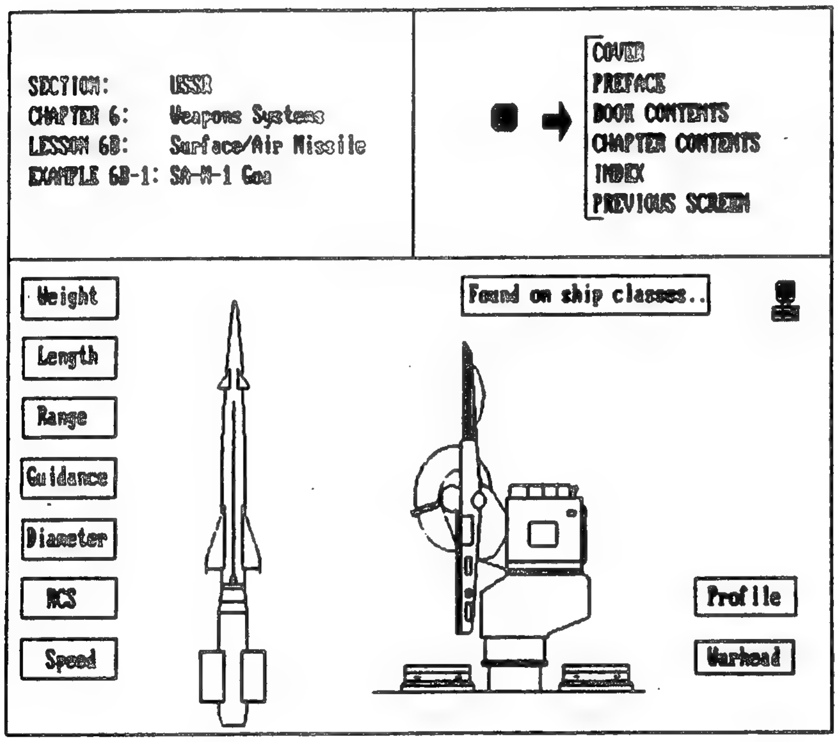
Information Pop-up Buttons
Click on either of these buttons to read more about its contents. When finished reading, click on the upper left corner of the pop-up box, and it will go away.

Chapter 6, "Weapons Systems"
Example page from lesson

Cognitive Map
This section shows exactly where users are in the lessson. It also shows the user how this lesson example fits into the total "Threat Matrix."

Navigation Buttons
Clicking on the first five buttons will take you to that identified section. Clicking on "PREVIOUS SCREEN" will allow the user to retrace you moves, and see up to 12 previous screens.

Line Drawing
If available for this example, a scanned line drawing will be shown.



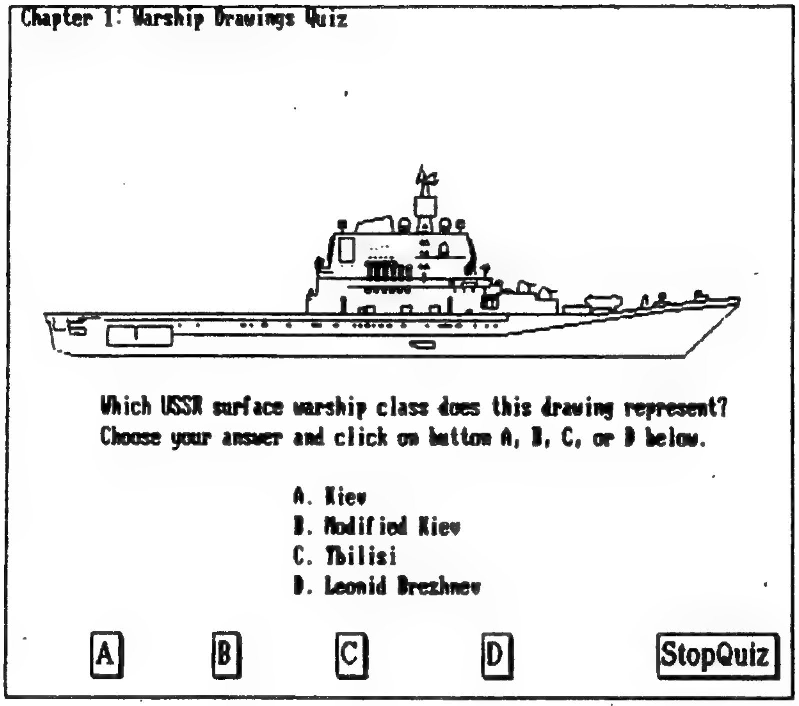
Video Buttons
If a green video icon is shown, clicking on it will show a motion video sequence from the videodisc. A red icon will show a still frame.

"TURN OFF VIDEO STILL" gives the user control of how long the video still image is on the screen

Information Pop-up Buttons
Click on any of these buttons to read more about its contents. When finished reading, click on the upper left corner of the pop-up box, and it will go away.

Sample Quiz Item
DRAWINGS

Quiz Identification
This section confirms the chapter and quiz type selected.

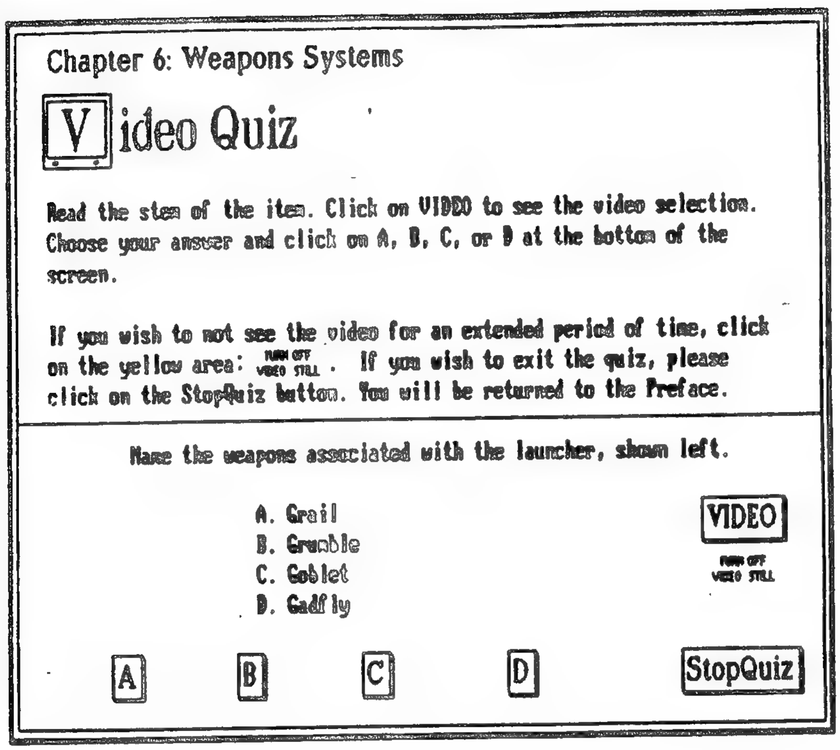


Response Selection Buttons
Click on box A, B, C, or D to record your response. A box will pop-up in center screen, to tell you if you are correct or not.

Stop Quiz Button
Clicking here will stop the quiz in progress, and return the user to the PREFACE page.

Sample Quiz Item
VIDEO RECOGNITION

Quiz Identification
This section confirms the chapter and quiz type selected.



Video Button
Click here to see the video sequence that goes with the quiz question.

"TURN OFF VIDEO STILL"
This button gives the user control of how long the video still image is on the screen.

Response Selection Buttons
Click on box A, B, C, or D to record your response. A box will pop-up in center screen, to tell you if you are correct or not.

Stop Quiz Button
Clicking here will stop the quiz in progress, and return the user to the PREFACE page.

A SYSTEMS APPROACH TO AUTOMATED TECHNICAL MANUAL DEVELOPMENT

INTRODUCTION

As tactical systems become more complex the paper technical documentation created to support them has grown in size and complexity. As a consequence, system operators and maintainers are faced with documentation storage problems, and a technical manual medium which has inherent limitations for accessing relevant information. This is especially true when using multiple volume technical manuals.

Recent advances in microprocessors, using rapid indexing response time and mass memory (approaching the 1 gigabyte threshold), have led to plausible, commercially available portable devices. In conjunction, the ability to apply "Expert System Programming" to the application software of an automated technical manual provides an increase in user efficiency. This is achieved by faster access and data retrieval time. Intelligently hypertexted automated technical manuals employ hypermedia principles to create workpackages that link specific sections of the technical manual in the sequence needed to correct maintenance problems or refresh knowledge of system operating procedures. The automated technical manual developers goal is to increase a user's technical abilities by "workpackaging" task oriented information within the technical manual. A workpackage allows the user to retrieve related data elements across technical manual volumes, in a prescribed sequence, to accomplish a task. Workpackages are at the core of Automated Technical Manual Functionality

DRIVE TO PAPERLESS

Space and weight have become more important as we push for more capability on smaller platforms. Paper, especially paper technical documentation, has long been targeted as a major space and weight driver. In 1987, GE proposed a completely paperless technical manual for the AN/BSY-2 Submarine Combat System, in response to the Navy's overwhelming desire to save space on the SSN-21 Class submarine. The BSY-2 is the largest, most highly integrated submarine combat system to date, and the estimated size of its technical manual is 50,000 pages. These 50,000 pages are roughly split between text and graphics. The Navy accepted our paperless approach, yet still required a paper manual to ease the transition from paper to paperless.

Because no automated technical manual specifications existed in 1987, the BSY-2 contract did not contain specific requirements nor specifications for the automated technical manual. Early in the program, GE agreed to write a system specification based on three high-level requirements.

a. The end-item device must be portable, weigh less, and consume less space than paper.

b. The paperless manual must provide all users with faster information access when compared to paper.

c. The information in the paperless manual must be identical to information in the paper version.

With these three top level requirements GE developed paperless manual specifications in accordance with what we now refer to as a "systems approach".

THE SYSTEMS APPROACH

A SYSTEMS APPROACH TO AUTOMATED TECHNICAL MANUAL DEVELOPMENT

The systems approach came about because of our desire to satisfy the unique needs of many customers and accommodate a wide range of maintenance and operational concepts, yet still have one basic process for creating an automated technical manual (ATM). The desire to have one basic process for creating an ATM is driven by economic considerations and a belief that simple, straight forward solutions are better than elaborate custom solutions. The desire to accommodate a wide range of maintenance and operational concepts is driven by the diversity of products GE build, documents and maintains. Our goal was to field a process that is easy and inexpensive to duplicate, would work equally well for all products, and not be constrained by obsolete technologies.

With the systems approach we identify customer needs and define how the ATM will be used to support a system, up front. Then we implement a solution to achieve it. The solution considers the total integrated logistics support picture for the tactical platform. It incorporates the maintenance concept, operational requirements, and training needs for the life-cycle of the tactical system. With the systems approach, technical logistics data and the ATM hardware and software are integrated to meet ILS and user requirements. This is accomplished by systematically analyzing user requirements, forming conceptual requirements, refining concepts into functional requirements, and developing system requirements that define how to tag data so it can be subsequently linked into work packages that support operational and maintenance concepts. This approach works equally well with new and existing technical manual data.

IMPLEMENTATION OF THE SYSTEM'S APPROACH

Once the systems approach has defined ATM functionality and how it will access information, it is necessary to author and tag the data. The tag set is composed of SGML tags. Creators of the automated manual must be subject matter experts (SMEs) on tactical system operations/maintenance, as well as being familiar with how the automated manual will be used. These subject matter experts embed their understanding of maintenance and operations into maintenance, operations and training routines using SGML tagged data. We call these routines "workpackages". The ATM developers goal is to increase a user's technical abilities by the workpackaging of task oriented information within the technical manual. A workpackage allows the user to retrieve related data elements across technical manual volumes, in a prescribed sequence, to accomplish a task. The sequence is defined by the subject matter expert using personal experience as well as inputs from Fleet personnel. The development of workpackages is the core of functionality of an automated technical manual. It is the difference between fielding an "electronic page turner" or a true expert-system operation, maintenance and training aid.

SMEs must be technically proficient in both the content of the technical manual and how it is to be presented; so that the manual imparts the greatest benefit to the user. Data elements (paragraphs, figures and tables) must be able to serve numerous workpackages. Knowledge of the tactical system combined with knowledge of the application software is the only way in which SMEs can effectively create workpackages. Often, SMEs have performed the tasking they are representing through workpackage construction. At minimum, workpackages should include maintenance and operational tasking. Training routines to support this tasking along with presenting basic knowledge of the system might also be included. In this way the manual can serve its purpose as a reference, problem solving, and training aid.

WORKPACKAGE UTILIZATION

Workpackages provide users with quick access to accurate data, helping them to solve problems faster. Because subject matter experts have already tagged task specific data, the need for users to leaf through paper manuals to solve maintenance problems or find operating procedures is eliminated.

The BSY-2 system, like most modern systems, has built-in performance monitoring and fault localization capabilities. When a failure occurs, an operator/maintainer is alerted with a fault code. To fix the failure, the maintainer enters the fault code into the automated technical manual directly, instead of fumbling through paper manuals in search of a fault code index. The fault code is hypertext linked to failure specific technical data, such as remove/replace procedures, functional block diagrams, circuit diagrams and troubleshooting routines. Procedures for these are supplied step by step with highlighted warnings and cautions, tools and parts lists and hypertext links to other applicable procedures. This helps ensure both thoroughness and accuracy in the performance of the maintainer.

Most military corrective maintenance concepts require a maintainer to localize and then remove and replace failed lowest replaceable units (LRU). If replacing the LRU does not solve the problem, the maintainer is automatically guided through more detailed documentation to continue troubleshooting the problem. Instead of having to sift through several paper volumes, the maintainer is supplied with additional reference material that is in the same workpackage format as the remove and replace procedure. The subject matter expert who created the workpackage drew on design experience and linked all related maintenance documentation in the workpackage for the maintainer. By simply entering one fault code, the maintainer has immediate access to all relevant data needed to solve his maintenance problem.

Operator workpackages function in the same way as maintenance workpackages. Operator workpackages are primarily used to refresh knowledge of specific operational procedures. Full understanding of functions, modes and system capabilities are also of great importance to operators. These elements of the technical documentation, as well depictions of displays, controls and indicators are all linked in operator workpackages. The operator workpackages are organized by functional watchstation. The benefit of operator workpackages is that they make it easy for operators to keep their system operational skills sharp.

Supervisor datapackages are organized and implemented in much the same way as operator and maintenance workpackages. However, supervisors need have access to data which relates to coordination or direction of system operation, preventative maintenance, and corrective maintenance. These datapackages incorporate general systems knowledge for those who may not have direct system responsibilities, but still require information to support training. Datapackages are not procedural in nature but informational. Datapackages are organized and linked by topic. These datapackages can also be used for watchstation qualification.

Training workpackages are the most unique of the workpackages. They provide embedded on-board-training of the tactical system using the technical manual. Subject matter experts, when composing the manual link together technical manual elements which meet tactical system training learning objectives. Training workpackages are used by instructors to encourage and improve the quality of student self study. After training, these workpackages are used to refresh and reinforce what they learned in the classroom. This process is enhanced using pop-up

windows containing instructor comments, as they would appear in an instructor's guide. At the end of each training workpackage the user is supplied with a hypertexted test reviewing the workpackage. If the user answers the question correctly he is allowed to proceed to the next question. If the user answers the test question incorrectly, the user is hypertexted to the point in the manual which addresses the question. In this way users can receive continuous training no matter where they are!

Another feature useful for training is the session replay mode. In the shore-based training environment, a significant portion of the training pipeline is dedicated to student familiarization of the organization and use of the technical manual contents. This contributes to the length of the training course and its associated costs. In the session replay mode troubleshooting problem-solving routines which are performed by the student can be stored on the automated technical manual. The instructor can then "play back" the technical manual references the student has used for a data-step by data-step review of the student's logic (an instant replay). This feature provides insight into the student's methodology for the instructor and immediate feedback to the student.

Other modes of operation, which supply user access in a more conventional fashion are:

- The main menu contains those modes of operation available to the user. The user selects the desired mode, the main menu bar (which allows user selections) changes relative to the mode of operation selected.
- The table of contents allows the user to view the table of contents, list of figures and list of tables per volume or for the entire technical manual. The technical manual elements are initially presented at a high level, volume, or chapter. These entries can be expanded by the user to include lower level paragraphs, figures, illustrations. All of the table of contents entries are hypertext linked to the appropriate manual element.
- The index functions allow users to view a list of topics for each specific volume. Each of these elements is hypertext linked to their appropriate manual element. The search function allows the user to type a character string and search through the full text or table of contents to find all occurrences of the string. This feature is available in all modes of operation.
- The browse mode allows the user to access any volume of the technical manual in a free manner. The user turns pages electronically until the point of interest is located. This mode functions like that of a paper text, only faster using hypertext links and the search function.

PAPERLESS MANUAL PRODUCTION PROCESS

Our experience shows that the quickest, least costly way to produce an automated technical manual is to utilize an electronic publishing system which provides a writer friendly environment where authoring, changes and revisions can be easily accomplished. The resulting technical manual data is stored as neutral ASCII SGML tagged files. The ideal system would be designed to output several mediums and be non-proprietary in its components.

SGML tags serve two purposes; they identify content and serve as workpackaging building blocks. The tags are translated or ignored by both the paper production process and the hypermedia software, depending on the tag. This structuring results in one production process which can output multiple media products. Paperless manual producers should also be concerned with the limiting aspect of proprietary data. ASCII files are understood by all publishing and hypermedia tools. It is a universal standard for character encoding. SGML tagging is a neutral and non-proprietary method to distinguish between the hypertext tags and data or content in the ASCII files.

Graphics are a large part of any technical manual and pose special consideration. There are basically two distinct sources of graphics for technical manual producers; engineering drawings and drawings created solely for use in

the technical manual. All technical manual images should be stored in a graphics data base, in a form which can be processed to provide either paper (postscript) or electronic (raster) output. It is not necessary that the input image format is the same, as long as its format can provide both outputs.

Once text and graphic format and storage problems are solved, text and graphics need to be linked together by SGML tags in the text and hypertext links attached to the graphic image. SGML tags in the text are used as pointers to indicate that a graphic image should be inserted at specified points in the text. The SGML tags also provide an address for text references to link to the image location. Hypertext links are placed on the image and linked to textual elements. All linking is done through the use of unique symbolic references which are given a physical address only when the data is translated for the electronic medium. This allows data to be inserted and deleted without requiring re-authoring of the links.

Configuration of the technical manual database must also be considered. The organization of a tech manual is a heirarchy of volumes, parts, chapters, paragraphs, figures, tables, and steps. For example, we are grouping in a directory structure, all chapters in a volume. Chapters are stored as a file. Numbered paragraphs are identified by a cross-reference tags which contain a unique symbolic name. Tables and figures are identified in the same manner. It is possible to extend this method to steps, warnings, cautions and notes. The symbolic name is used by authors to cross-reference elements in the technical manual text. It is also used by subject matter experts to script work packages.

END ITEM CONSIDERATIONS

We call the end-item device for the automated technical manual an Alternate Media Display (AMD). The requirements for AMD selection are identified and analyzed using the systems approach which ensures that end users and their needs are fully considered. The results of this analysis are translated into functional requirements that are then used to perform a technology search to find candidate AMDs. The AMD candidate that meets the largest number of requirements is selected. The tactical environment will dictate the degree of ruggedization required by the AMD. For example, the submarine environment is not nearly as hazardous, on portable electronic equipment, as a carrier flight deck. Therefore, it may be more cost effective to purchase a Commercial-Off-The-Shelf (COTS) device rather than investing in ruggedization.

AMD software must provide the data retrieval function and complement the AMD's man-machine interface. Several COTS products are available that provide this capability. Many products provide browsing functions that allow the user access to data through Table of Contents, Index, and menu functions. Many of them also provide some capability to link cross referenced data with hypertext. We chose a combination of two software programs that work together to provide these functions and allow us to easily construct workpackages.

In creating an AMD one should avoid customized and project- unique solutions because they are costly and constrain you to a single technological solution. On the BSY-2 we decided to go with COTS products because they are inexpensive, modular, and allow customization. By doing this, we developed a flexible automated technical manual system. Modular COTS products can be replaced, if required, to meet unique project needs. Most importantly this process allows ATM developers to float with technological advances! This ensures that the automated technical manual uses the most current technologies throughout the life-cycle of the tactical system.

CONCLUSION

Technology for creating and fielding automated technical manuals is here today and it makes sense to apply this technology on large systems having multiple volume technical volumes. The key to cost effective implementation is to use a systems approach and COTS products. The systems approach reduces development risk by integrating operating and maintenance concepts with user needs to ensure that what you field is what is needed. COTS hardware and software lets you float with technology until it is time to actually field the automated technical manual.

Creating an Automated Technical Manual is easily within the capabilities of most contractors and provides a large, measurable increase in operator and maintainer effectiveness.

-CONCEPT PAPER-

INTERACTIVE BEHAVIOR CONTROL SYSTEM (IBCS)

PROTOTYPING SYSTEM DEVELOPMENT

NOVEMBER 1991

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-ABSTRACT-

A PROTOTYPING SYSTEM FOR SIMULATION ENTITY INTERACTIVE BEHAVIOR CONTROL

Across the DoD weapon systems engineering and tactical training communities there is a joint requirement to simultaneously reduce the cost and increase the realism of interoperability training exercises. One approach to achieving this joint requirement is to replace specific subsets of the manned interoperational contingent (operational platforms or manned trainer ("player") stations) with computer-controlled entity simulations.

To date three techniques have been used to implement computer-controlled entity simulation in an attempt to reduce the number of manned trainer "player" stations:

- Instructor-Controlled Simulation
- "Semi-Automated Forces" (SAFOR)-Controlled Simulation
- Autonomously-Controlled ("Intelligent") Simulation

Each of these three simulation techniques has shown varying degrees of benefit depending on the operational dynamics and/or behaviors required for training.

This paper presents a design concept for a fourth technique for computer-controlled entity simulation: that of Supervisor-Controlled Simulation. Supervisor-Controlled Simulation places the human in the role of a supervisor of semi-autonomously-controlled simulation entities. As a supervisor, the human is able to intervene in the otherwise computer-controlled deductive reasoning and procedure control processes to assist the subordinate in situation assessment and tactical goal selection. The human intervention enables a degree of inductive reasoning and human "unpredictability" to be injected in the simulated entity behavior. This paper also presents the requirements and top-level components for a Supervisory Control simulation test-bed called the Interactive Behavior Control System (IBCS). The supervisory control simulation test-bed must be developed to enable the evaluation of alternative concepts for "leveraging" human reasoning across a large and potentially diverse set of otherwise computer-controlled simulation entities.

The Supervisory-Controlled Simulation design is being pursued in a multi-year IRAD program by Ball Systems Engineering Division. The concept of supervisory control simulation is beneficial for individual or team training simulation systems configurations. The supervisory-control concept provides a "sliding scale" of simulated entity control: from complete control by the instructor to fully-autonomous interaction.

DESIGN REQUIREMENTS

The top-level requirements for the IBCS concept fall into two categories: (1) functional and (2) computational. The functional requirements for the IBCS concept include the following:

- Provide realistic command and control dynamics simulation for all critical training cues associated with all classes of semi-automated simulation entities.
- Provide for supervisory intervention in any of the entity's on-going command and control processes.
- Maintain simulated entity real-time performance (both in decision-making and systems control directives) for all the simulation entities under the IBCS control.
- Avoid unrealistic/extra "Situation Awareness" to be available to the supervisor for any simulation entity.

The computational requirements for the IBCS concept include the following:

- Support a hybrid of simulation entity decision-support software including: (a) decision-theoretic and/or utility theory algorithms; (b) real-time expert systems; (c) neural networks; and (d) mathematical programming.
- Support training instructor direct simulation entity control modes.
- Support an object-oriented interface to the simulation entity's subsystem control simulation software.
- Support distributed interactive network interfaces.

The level of realism required for computer-controlled threat simulation is driven by the operational accuracy with which tactical-decision-making "cues" must be statically and dynamically represented to the trainee. The simulation realism required for realistic cues is a function of the sensitivity/observability of the trainee's on-board sensors and communication systems as well as the expected interaction dynamics that operational players and simulation systems can have within large-scale interoperability simulation training exercises. Table 1 characterizes four "interaction states" that differentiate the simulation entity control systems that could be expected to provide "cue realism" to the trainee positions on the simulation network. IBCS should be configured to control all entity interactions with the trainee that do not require continuous explicit communication and/or "ACM-level" operator reasoning.

The IBCS must be designed to interact with the manned positions on a distributed interactive network. The networking approach to distributed interoperability training can be expressed in simplified fashion by the diagram in Figure 1. Figure 1 displays three categories of networked systems: primary training

systems, secondary training systems, and supplemental training systems. The primary and secondary training systems are defined to be "manned systems" that may be linked to each other by data links (simulated or operational) and/or communication channels. The supplemental training systems provide additional interoperability realism and can be made up of a hybrid of manned and unmanned simulation entity controllers.

The supplemental systems can be further partitioned into three categories: (1) Semi-Autonomous Forces (SAFOR) control simulation systems; (2) Supervisory control simulation systems; and (3) Autonomous control simulation systems. The semi-intelligent simulation entities associated with the SAFOR commander's position must be functionally responsive to the SAFOR commander's simulation state dynamics (see References 1 and 2). The semi-intelligent simulation entities associated with the IBCS concept are responsive to a combination of the supervisor's directives and computer-generated procedures directives. The difference between SAFOR control and Supervisory control is that the supervisor is not a direct war-fighting participant and is "free" to intervene across a spectrum of simulation entities, where as, the SAFOR commander is a war-fighting participant and is obligated to man his position, thereby, reducing the SAFOR Commander's capacity (during high task-loading situations) to provide explicit semi-autonomous control intervention.

TABLE 1 - TRAINEE/ENTITY SIMULATION CONTROL STATES

TRAINEE/THREAT INTERACTION STATE	SIMULATION ENTITY CONTROL TECHNIQUE
Threat ACM or Close Formation Communication and Coordination	Individual MIL* Simulation Stations Required
Secondary Player to the Primary Team C3I Interaction	Low fidelity MIL and/or Semi-Autonomous Simulations
Entities Inside the Ownship's Immediate Offensive or Defensive Planning Envelope	Semi-Autonomous Simulations
Entities Outside the Ownship's Immediate Offensive or Defensive Planning Envelope	Autonomous Simulations

* MIL - Man-in-the-loop; Semi-Autonomous - human-assisted computer-controlled simulations; Autonomous - no human assistance in the entity control simulation

To have the greatest utility, the IBCS concept must free-up the instructor while at the same time providing a degree of human-like behavior to a set of entities that are most critical to the trainee's tasking. The human-like behavior should be achieved by a blend of autonomous expert-systems-like procedure controllers and aperiodic human reasoning (see reference 3). The overall IBCS control concept must be partitioned to enable model validation and certification in the context behavioral-associated software processes (perception, reasoning, decision-making, and procedure control) (see Reference 4). Lastly, the IBCS concept must embody the principles of supervisory control (see Reference 5). The key design trade-off is the sophistication of autonomous deductive reasoning systems and the design of a real-time human-to-expert systems interface.

To be effective, the supervisory control interface must support three primary processes: (1) supervisor's receipt of subordinate requests for advice and direction; (2) subordinate's receipt of supervisor's advice and direction (provided in a timely and contextually-meaningful set of goals and objectives); and (3) a subordinate activity simulation that transforms the goals and objectives into explicit systems procedural command and control activity as a function of both the immediately perceived situation and the goals and objectives (see Reference 5).

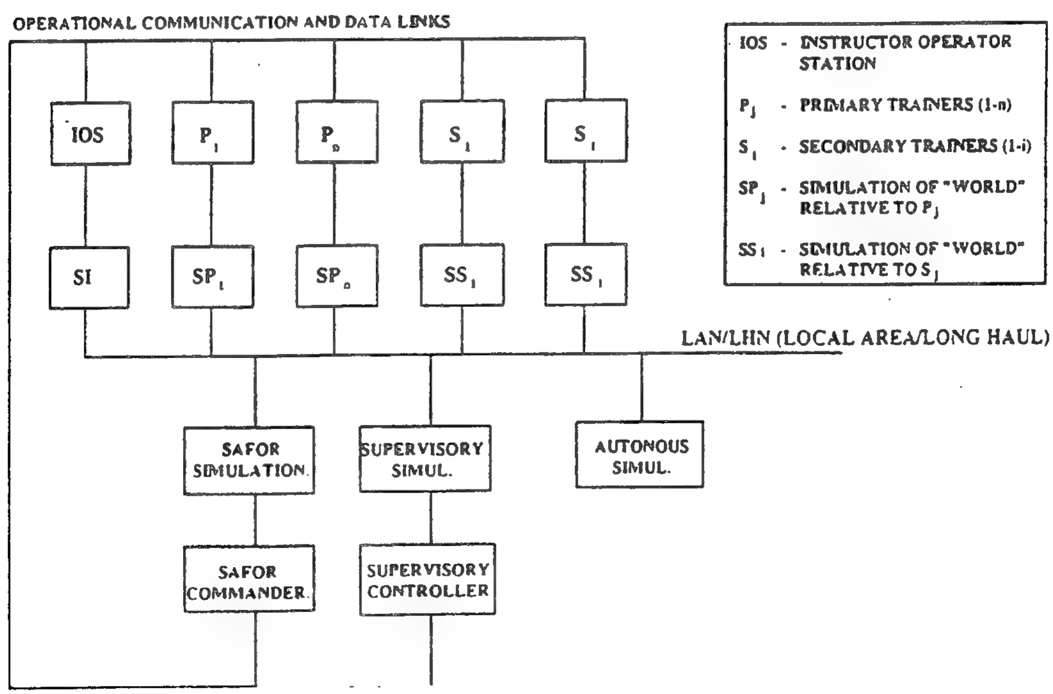

FIGURE 1 - DISTRIBUTED SIMULATION CONTROL COMPONENTS

CONCEPT OVERVIEW

The IBCS design is comprised of three simulation processes:

- World State Update Simulation
- Human Activity Simulation
- Human Intervention Simulation

The goal of the supervisory control mode is to provide timely management directives where appropriate while avoiding the requirement for micro-management. The appropriate stages of intervention will be determined by "assessing" the need (utility) to apply human inductive reasoning to assist the subordinate human activity simulation in making "realistic" decisions. The supervisor will be prompted to intervene within the simulated entity's decision-making state in an operationally-consistent manner. The "options" for and the timing of these interventions will be under the joint control of the computer-based human activity simulation and the human intervention simulation. Figure 2 provides an overview of the critical information flow between the primary simulations that comprise the IBCS.

The cornerstone of our approach is the co-execution of supervisory control simulation and human activity simulation modules. The supervisor is afforded direct access to the human activity simulation module processing and the human activity simulation is jointly responsive to the supervisor's directives as well as its own dynamic assessment and control processes. Providing for supervisory control means that the embedded expert systems that control the simulated human activity can be oriented toward the deductive behavior processes while the supervisor can be prompted to intervene in the human activity simulation to interject inductive reasoning. The separation of the inductive and deductive reasoning processes is a critical aspect of our concept.

The IBCS will develop and display "intervention cues" and intervention "state data" to the supervisor via the Human Intervention Simulation (HIS). <u>The intervention state data will be directly accessible and augmentable by the supervisor for any simulation entity whose dynamic behavior is projected (via situation uncertainty (novelty) detection) to benefit from the direct application of human judgement</u>. If no intervention cue is generated and/or no intervention action is initiated, then entity command and control will be maintained by the entity's autonomous-control simulation. The functional interaction between the primary computational components of the IBCS processors is displayed in Figure 3. A brief description of these IBCS components is provided in Table 2.

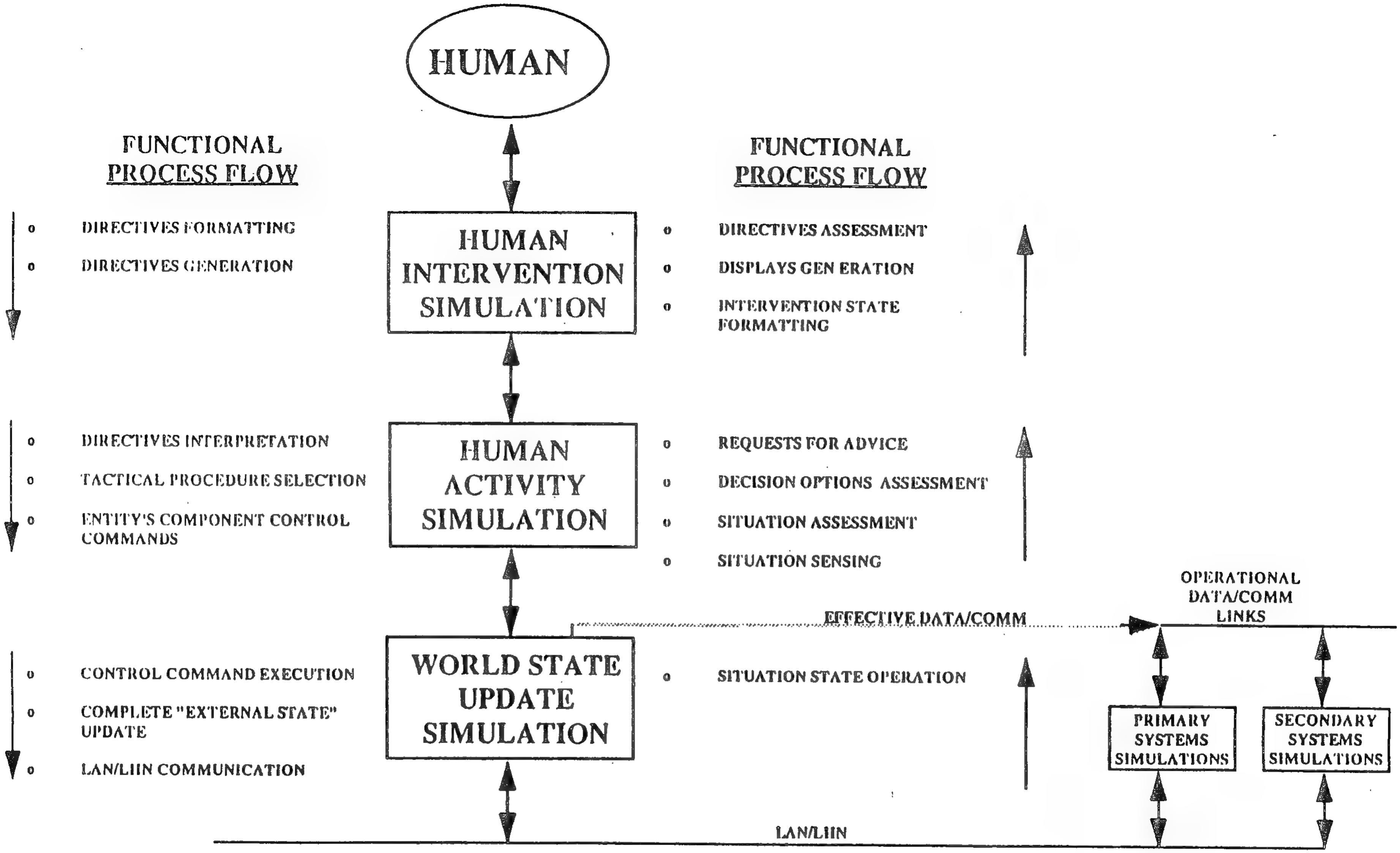

FIGURE 2 - SUPERVISORY CONTROL SIMULATION CONCEPT

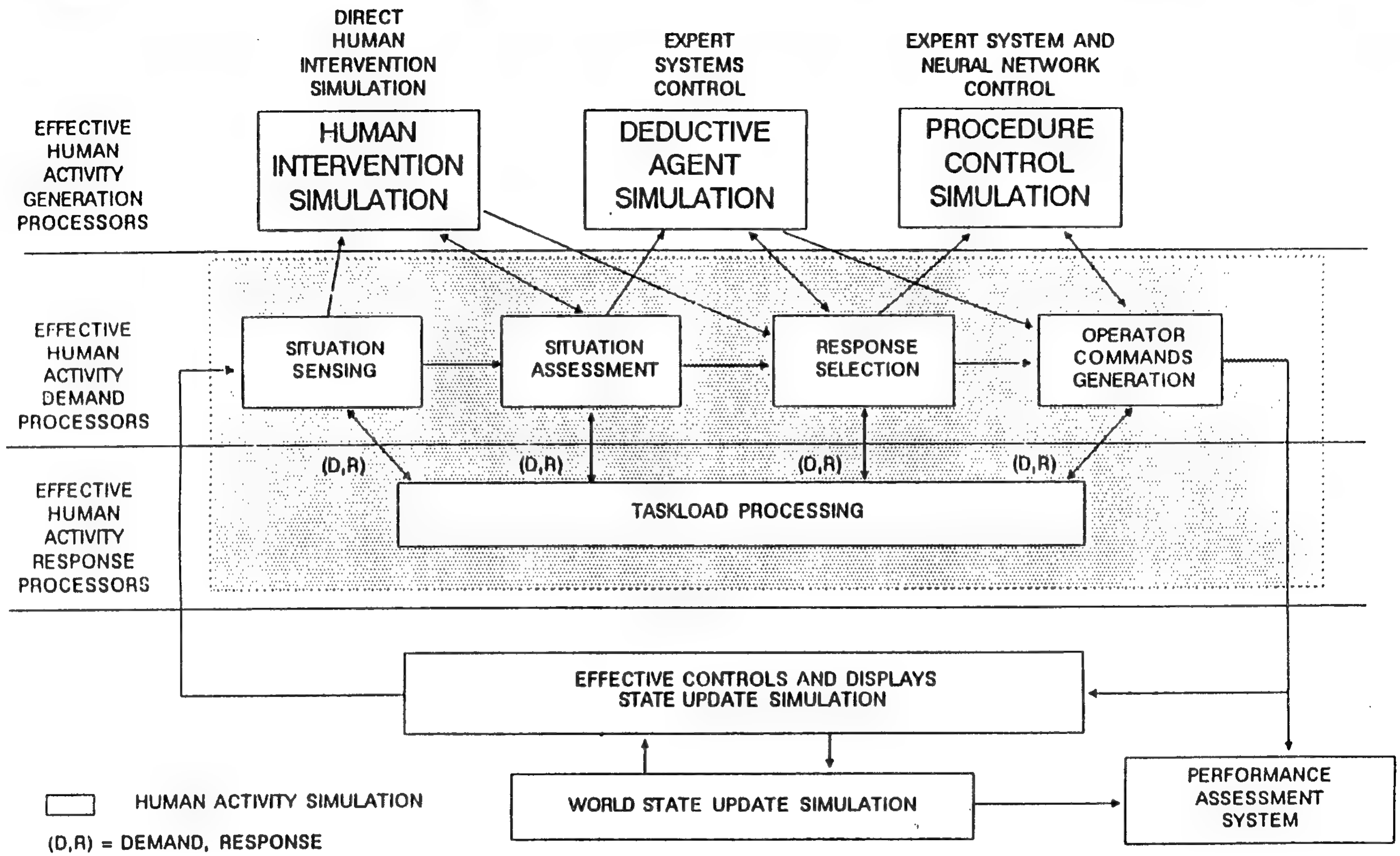

FIGURE 3 - INTERACTIVE BEHAVIOR CONTROL SYSTEM FUNCTIONAL FLOW

TABLE 2 - IBCS COMPONENT DESCRIPTIONS

Human Activity Simulation (HAS)	Simulation of effective human task activity execution based on human multi-resource supply and demand
Human Intervent. Simulation (HIS)	Simulation the translates the current HAS state and request for intervention into "effective" entity Situation Awareness for the supervisor. HIS also provides the supervisor's controls/displays interface simulation to enable intervention advice to be generated in terms that the HAS can interpret.
Deductive Agent Simulation (DAS)	Expert-systems-based simulation of weapon system response selection. Response state is a function of the assessed operational situation and the current mission state utility of the alternative weapon systems responses.
Procedure Control Simulation (PCS)	Provides simulated weapon system(s) control update for procedural tasking requiring no intervention command/control
World State Update Simulation (WSUS)	Provides for all simulation entity state updates in response to control commands generated by HAS and PCS
Effective C&D State Update Simulation (ECDS)	Manages explicit WSUS command generation and generates effective situation stimuli to drive the HAS model
Performance Assessment System (PAS)	Develops the correlation of human and computer-aided situation assessment to simulation entity state dynamics repres.

The key processes of the IBCS concept are the Human Activity Simulation (HAS) and the Human Intervention Simulation (HIS). The interaction between HAS and HIS provide the human-like behavior to the simulation entities. The functional HAS processing elements (shown in Figure 3) are described in Table 3. A critical component of the HAS is the Taskload Processing simulation. The Taskload Processing simulation uses multi-resource theory to constrain the operator's effective task completion throughput (see Reference 6).

TABLE 3 - HUMAN ACTIVITY SIMULATION ELEMENTS DEFINITION

Situation Sensing	Translates situation state data that would be available to the operator into operator-detected state data. The data is formatted into situation assessment data for use by the Situation Assessment process as well as the HIS.
Situation Assessment	Simulates: (1) the process of developing the operator's active hypotheses of the current mission situation; (2) testing the sensed situation data against the active hypotheses; and (3) selecting an operative hypothesis based on confirming evidence. This process is augmentable by the HIS.
Response Selection	Simulates the decision-making for future weapon systems command and control based on the currently-active operative situation hypotheses. This process evaluates alternative tactical response options and selects the preferred option for execution scheduling.
Taskload Processing	Simulates the operator's explicit completion rate of task activity associated with the operator's required weapon system command and control processing.
Operator Commands Generation	Simulates the prioritization and scheduling of weapon systems command and control activity associated with the response selections from the Response Selection processor. Sets database elements associated with the ECDS and WSUS interfaces.

The HIS will enable a human (Supervisory controller) to directly or indirectly intervene in the on-going computer-based command and control process at critical times. Direct intervention in the command and control process means that the supervisory controller would be provided specific/timely situation stimuli that would be operationally present (ie. from displays, data links, and step-stare out-the-window scene generation) as a function of the simulated operator's on-board "vision" process. Indirect intervention in the command and control process means that the exercise controller would receive and enable or augment pre-processed situation assessment state data (network graphics depicting both current and historical time/event activity) for the intervened entity. HAS will continually form and test active situation state assessment hypotheses as a part of the HAS Situation Assessment (SA) processor. If the supervisor intervenes within the entity's SA process, then he will be provided both computer-based active and operative hypotheses associated with the currently prioritized entity command and control state. When the human does not involve himself in the command and control process, the HAS will provide real-time computer-based intelligent systems command and control to the WSUS to "close-the-loop". The WSUS component of IBCS will execute the control commands independent of whether these commands come from the human or from the computer-based intelligent systems. The Human Intervention Interface processes are displayed in Figure 4.

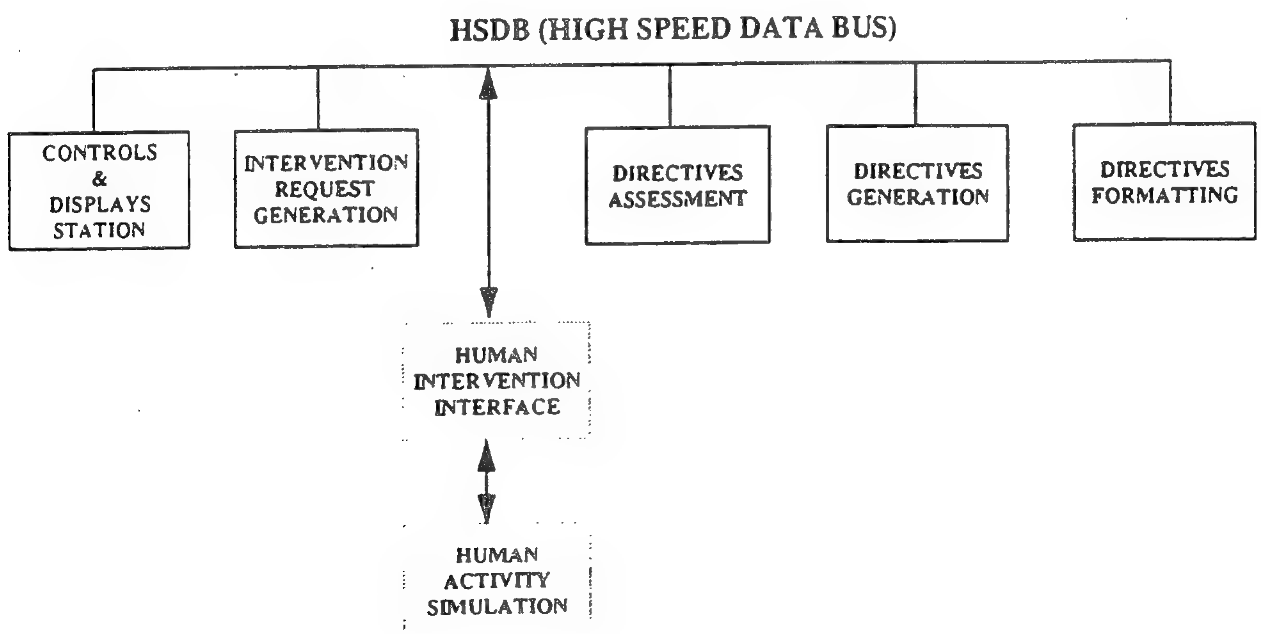

FIGURE 4 - HUMAN INTERVENTION SIMULATION PROCESSES

Figure 5 highlights 3 alternative "states" of control for which the IBCS would generate 3 different levels of simulation processing. The activity flow associated with each set of simulation processing highlights the interaction between the primary IBCS components. Figure 5 distinguishes 3 simulation "conditions" where different states of human intervention can be applied to increase the realism of the simulation entity's performance and appearance.

PROTOTYPING ACTIVITY

Ball Systems Engineering Division is developing a system to prototype the IBCS under a three year IRAD program. The IRAD program began in 1991. The prototype IBCS will be developed to enable extensive supervisory control mode testing in a stand-alone configuration or in a networked system with other distributed interactive simulation (DIS) control network nodes that have been developed. Figure 6 diagrams the components of the IBCS in conjunction with other Local Area Network (LAN)-connected DIS processors.

Our approach toward developing the IBCS prototype is divided into four phases:

- Phase 1 - Design Requirements
- Phase 2 - Core Systems Development and Demonstration
- Phase 3 - Human Intervention Simulation Development and Integration
- Phase 4 - Network Interface Development and Concept Verification Testing

The total IBCS prototyping program will be structured to configure an IBCS demonstration version by the end of 1992. A user-verified test system will be developed by 1993. The mission domain for the user-verified test system will be a Helicopter-Airborne Forward Area Control mission. Enough detail regarding the critical mission element scenario dynamics will be simulated to demonstrate the feasibility and flexibility of the IBCS Supervisory-Controlled Simulation concept.

PLAUSIBLE INTERVENTION STATES

CONDITION 1	CONDITION 2	CONDITION 3
A's SA of B is highly dynamic and unpredictable	A's SA of B is highly dynamic and predictable	A's SA of B is constant

IBCS ACTIVITY FOR EACH CONDITION

Condition 1

- HAS computes feasible SA states and requests human intervention
- HIS interprets HAS request and formats the current control state of B relative to A for human intervention
- Supervisor selects one of the feasible SA states for B
- HIS transforms human selection into data elements for use by HAS
- HAS develops set of entity tactical proceduresds based on HIS state selection
- DAS and PCS generate explicit state control commands

Condition 2

- HAS computes "best" SA state and passes info. to DAS
- DAS computes tactical procedure alternatives and evaluates benefits of each alternative
- DAS computes priority for initiating the best alternative
- PCS schedules the execution of specific procedure controls

Condition 3

- DAS computes tactical and procedure alternatives and determines there is no value in changing current PCS procedures
- PCS continues to manage execution of response option recommended by DAS

NOTES:
SA – SITUATION ASSESSMENT
HAS – HUMAN ACTIVITY SIMULATION
DAS – DEDUCTIVE AGENT SIMULATION
HIS – HUMAN INTERVENTION SIMULATION

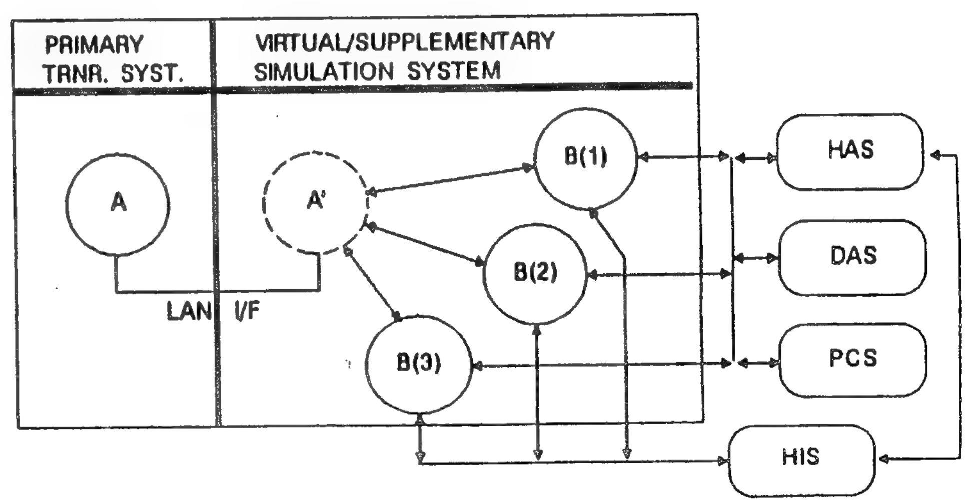

FIGURE 5 - SAMPLE INTERVENTION STATES

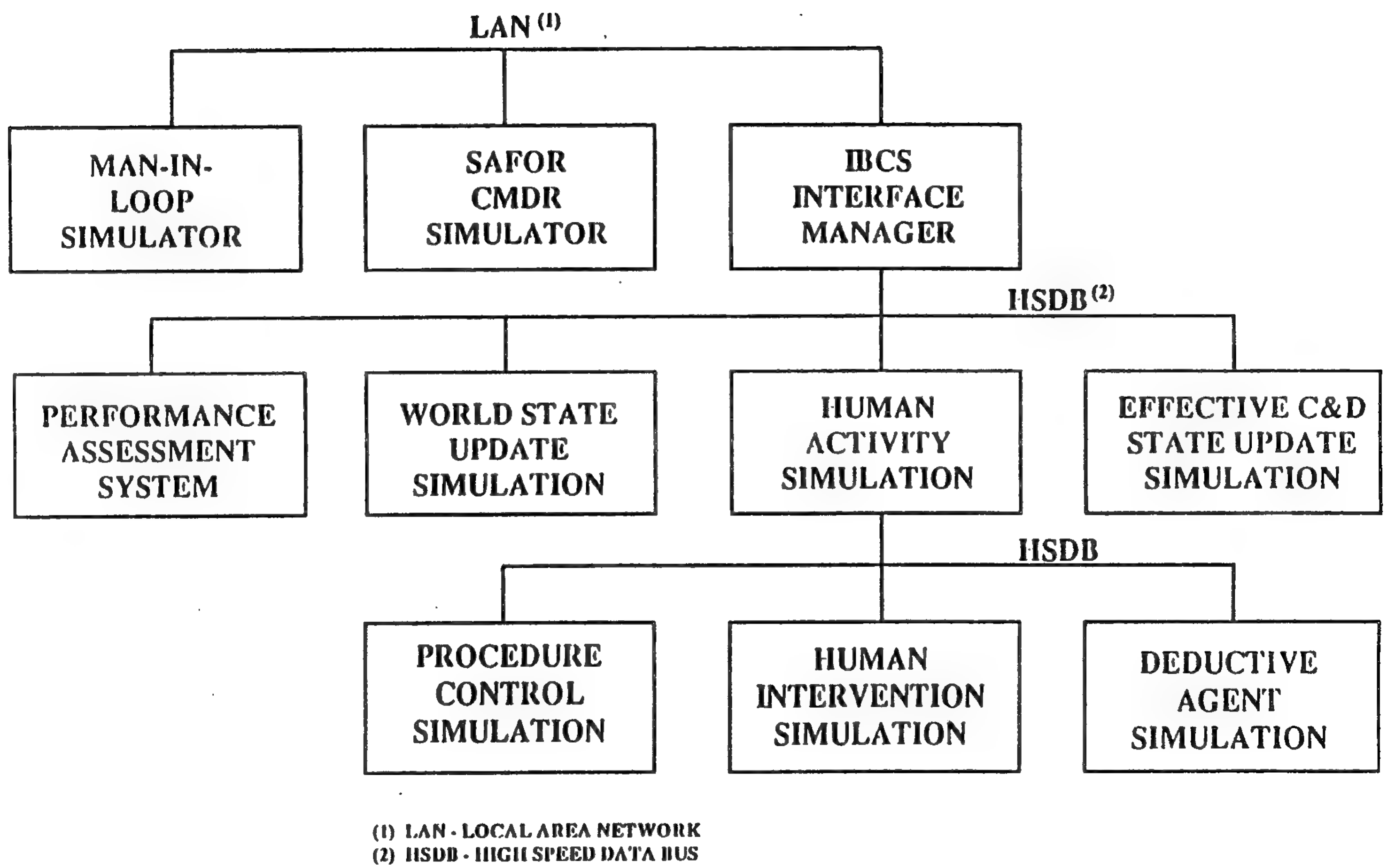

FIGURE 6 – INTERACTIVE BEHAVIOR CONTROL SYSTEM PROTOTYPING SYSTEM

RELEVANCE TO OVERALL TRAINING RESEARCH OBJECTIVES

The IBCS concept offers the potential for three main benefits: (1) a periodic human-in-the-loop performance (explicit allowance of unpredictability and reasoning under uncertainty); (2) a reduction in required complexity for expert systems entity controllers (by reducing the need for the representation of uncertain inductive reasoning within the expert systems); and (3) a simulation testbed whose architecture will permit an efficient validation process (due to a behavior-theory-compliant systems architecture).

The IBCS will complement the SAFOR Commander's Station and enable substantial numbers (100's) of intelligent simulation entities to be maintained as realistic "players" in the simulation for extended periods of contiguous time/event space by a single supervisory controller. These intelligent players may even be linked via the currently-developed SAFOR command and control structures to create a multiplying effect for intelligent control of up to 1000's of players. The implementation of "fast moving platforms" and highly dynamic situation assessment processing into the distributed interactive simulation training domain will benefit from the IBCS concept.

Successful development of the IBCS will enable the derivation of mission-segment control strategies and associated data bases that maximize the set of computer-controlled entities that can effectively be managed by a single human instructor/operator. Properly configured and dynamically managed, these mission-segment-specific databases can be linked during interactive simulation to form composite human/computer-based mission level command and control policy sequences. These sequences would form the control strategy database for the Human Intervention Simulation (HIS). Through iterative testing and database maturation, the HIS would be reconfigured in conjunction with the HAS and the WSUS to form the basis of training-application-specific "Interactive Adversary Control Systems" (IACS). These IACS would form the kernel for a large set of simulation-centered weapons engineering and DIS systems that require complex large-scale intelligent adversary simulation design environments.

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MISSION SYSTEM TRAINING THROUGH THE NETWORKING OF TWO WEAPON SYSTEM TRAINERS (U.S. NAVY DEVICE 2F146)

A Paper for the Third Annual Airborne
Weapons Technology Review and Training Exposition

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ABSTRACT

Linking independent task trainers together to provide complete crew training has become a growing simulation requirement. The SH-60F Weapon System Trainers (WSTs) allow the traditional integration of an independent Sensor Operator Trainer (SOT) with an independent Operational Flight Trainer (OFT) to yield a Weapon System Trainer. It then takes this training scenario one step further by networking two WSTs to create a Mission System Trainer (MST) to enable coordinated training for two anti-submarine warfare (ASW) crews in a common tactical problem world. Within such an environment, the effects of another crew's actions in the scenario are generated by each crew directly, requiring no simulation on the part of the instructor.

The MST mode of operation furnishes advanced training capabilities in aircraft to aircraft communication for areas of datalink, VHF/UHF, clear and secure, HF, air to air TACAN, and underwater communication. Acoustic interference can be created with both WST's dipping sonar, as well as having multiple sonobuoys on the same sonar frequency. Formation flight training is enhanced by the unpredictability of the other aircraft's movements and the availability of full collision detection between the two helicopters. Training scenarios in the MST mode can extend to the training of multiple crews in coordinated take offs and landings from a common parent ship and the synchronization of tactical maneuvers in an ASW search within the inner zone.

The mechanism of connecting the WSTs is a unique Ethernet protocol developed by Reflectone, and through the direct connection of the WST's Tactical Data Systems for the purpose of datalink. Although all four trainers (2 OFTs and 2 SOTs) are controlled by their own instructor station in independent mode, MST mode allows for total problem control from either WST instructor station. From the instructor station selected as the command station, the problem world (target types and positions, problem world limits, weather, ocean type, biologics, etc.) is created in the same manner as for a single WST, except that now it is made common to both trainers. The individual environment of the trainer such as ordnance load, malfunctions, and fuel quantities is still maintained by means of a helicopter designator function. This function also directs the instructor control over the individual trainers in such areas as parameter freezes, slew control, motion and hydraulics.

The technical modeling implementation, which permits these trainers to grow from a single task trainer to a complex mission trainer, allows for highly diversified training capabilities. In this way, advanced coordinated ASW crew training, previously unobtainable in a simulation environment, is now a viable option.

INTRODUCTION

Increased budget constraints, accompanied by the need for a higher level of training in conditions which cannot be duplicated in peace time manuevers and "team" training requirements have made it necessary to develop simulators capable of rendering more than the basic training they have traditionally provided. Networking single task trainers into mission oriented training systems is a low cost, highly effective method of acheiving this goal. The networking of a large number of low cost trainers into a common battlefield for ground combat training has been demonstrated by SIMNET [1]. Air-to-air combat training is available in simulation through the MULTISIM program at Fort Rucker [2]. Now, the networking concept has been applied to advanced coordinated ASW crew training in the SH-60F (CV-Helo) Mission System Trainer.

The CV-Helo Weapon System Trainer's requirement is "to provide the functions and equipment necessary to train the Pilot, Copilot and

Sensor Operators in the familiarization, normal and emergency operational procedures and tactics of the SH-60F mission," as well as provide proficiency training for the aircrews [3]. The full-fidelity OFT and SOT, when used independently, provide the basic and SOT, when used independently, provide the basic training for NATOPS qualification. Additional total-crew training is provided by combining the two trainers into a WST. However, in certain realms of the SH-60F's primary mission of inner zone anti-submarine warfare, effective proficiency training would not be acheived in the training of a single crew. Consequently, it was additionally specified that the two WST trainers have the added capability of being linked together to create an MST trainer.

With MST mode, it becomes possible to train, through simulation, the methods of dual team coordination in the search, detection, classifiation, tracking, and prosecution of the underwater threat. All aspects of the dual WST interaction, that are essential to this task, are functional in both trainers.

SYSTEM OVERVIEW

TRAINER LAYOUT

The complete CV-Helo simulator system consists of five trainers, each driven by their own computer and each having their own instructor station. The five trainers comprising the system are two OFTs, two SOTs, and an Acoustic Trainer (AT). Figure 1 depicts the training system configuration. All five computers are linked via Ethernet. Additional hardware connections exist for the communication systems and the motion and hydraulics controls, as well as the physical connection of the 1553 data buses for Data Link transfers. The information packets sent over the Ethernet and the enabling of the hardware connections are determined by the training mode.

Training modes are selectable from the instructor stations, with the default mode upon trainer activation being independent operation. The only prerequisite to placing trainers in integrated modes is that all trainers for that mode be online and in total freeze. Modes are also prioritized so that one trainer cannot be "stolen" out of a higher priority mode. All possible training mode combinations are listed in Table 1.

All trainers can be run simultanously in their independent mode. Each OFT may also be combined with its corresponding SOT to create a WST, or all four trainers may be joined together in an MST mode. The SOTs may also be networked with the AT to provide additional AT stations (AT-Coupled mode), as well as with each other to produce a combined SOT mode.

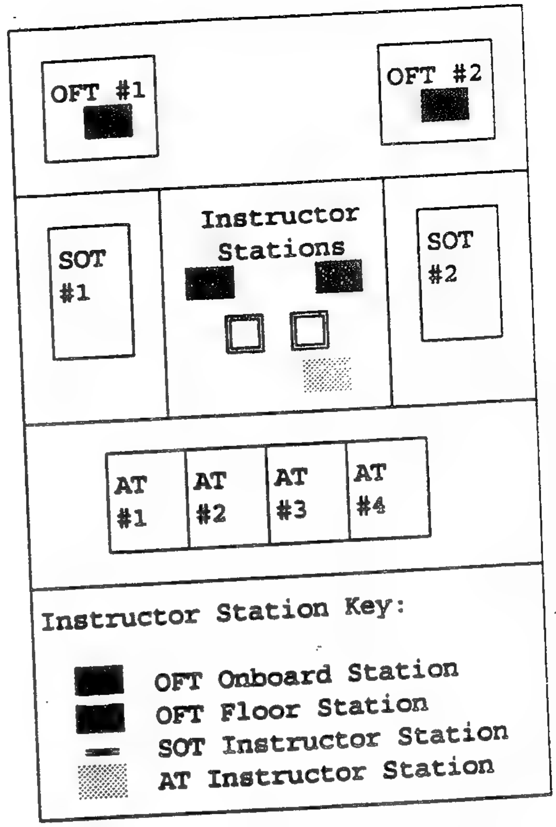

FIGURE 1. Training System Configuration

	1	2	3	4	5	6	7	8	9	10	11
OFT #1	I	W	M	I	W	I	I	W	I	I	I
SOT #1	I	W	M	A	W	A	S	W	I	A	I
OFT #2	I	W	M	W	I	I	I	I	W	I	I
SOT #2	I	W	M	W	A	A	S	I	W	I	A
AT	I	I	I	A	A	A	I	I	I	A	A

Mode Key:
I: Independent
W: WST
M: MST
S: SOT Combined
A: AT Coupled

TABLE 1. Integrated Mode Configurations

The OFT for each WST is a simulated cockpit with an eight window/six channel visual system, mounted on a six-degree-of-freedom motion platform, capable of training both a pilot and copilot. The fully equipped onboard instructor station is used for the control of the training scenario in the OFT independent mode only. An equivalent floor instructor station, is used in conjunction with the SOT instructor station for controlling the WST scenario.

The SOT trainee station is a fixed base shell containing the Tactical Sensor Operator (TSO) station and the Acoustic Sensor Operator (ASO) station. The SOT instructor station is used in controlling both the independent mode and the WST training mode.

In WST mode, the OFT and SOT students work together as in the real aircraft. Parameters generated through instructor control during independent mode are now replaced by the actual elements resulting from the combined crew's actions. For example, helicopter position, altitude, and speed which are instructor input variables in SOT independent mode are now determined by the simulation output of the OFT. The division of labor between the OFT and SOT instructor stations, when operating as a WST instructor station, is such that the SOT station controls the tactical problem world, while the OFT station commands the aircraft and its environment. Parameters which are selectable on both trainers such as sea state can still be modified from either station.

MST FEATURES

The MST mode is simply the interaction of two WSTs in a common problem world. The WST instructor station from which the mode is requested becomes the command station, and is now capable of controlling both WSTs. The key feature of MST control comes from the fact that although both WSTs interact in the same problem world, governed by a global freeze and a single initial condition, the autonomy of each helicopter is retained by the instructor through the use of a helicopter designator function. The following is a list of features accomplished from a single command station which allow changes and reconfiguration of one WST without interrupting the other WST when in the MST mode:

1) Motion and hydraulic systems operate independently for each OFT.

2) Parameter freezes including flight, position, altitude, speed and fuel affect each WST individually.

3) Slew functions are applied selectively to each WST.

4) Separate GCA/CCA/DCA appraoch plots can be obtained for both WSTs.

5) System malfunctions/degradations and aircraft emergencies are inserted into each WST individually.

6) Helicopter configurations, including armament, sonobouys, and sonar/cargo hook are managed separately.

Although the above controls are applied separately to the individual WST, instructor control of the tactical problem world such as target activation and environmental parameter manipulation need only be entered once to be applied to both WSTs.

The MST mode of operation furnishes improved training capabilities in three major functional areas:

1) Communications : The instructor is able to communicate with both crews through the ICS, either selectively by trainee position, or with all crew members simultaneously. WST to WST communication may be accomplished via VHF/UHF normal and secure, HF, or by means of UQC (underwater communications) from dipping sonar to dipping sonar. Range and bearing calculations are achievable through air to air TACAN. In addition, the Tactical Data Processor Data Link can be accomplished between WSTs.

2) Formation Flight : Coordinated flight, including takeoffs and landings from a common parent ship is available to both WSTs in the MST mode. Each aircraft can be seen in the other's visual scene and automatic collision detection is acheived through the sensing of the intersection of the two helicopter volumes.

3) Acoustic Effects : Sonobouys launched by either helicopter into the tactical problem world can be monitored by both WSTs. In addition to the traditional acoustic interference caused by two sonobouys having the same ensonifying frequency, the MST mode also allows for direct path acoustic interference of the two dipping sonars.

DESIGN CONSIDERATIONS

The requirements for the integrated modes on these trainers demanded several special design considerations. The data being conveyed over the Ethernet must be transferred at a high enough rate to keep the fidelity of the simulation intact, yet still keep the Ethernet traffic to a minimum to reduce collisions and deferred frames. The fifty percent spare time restriction on the trainer loads also makes it imperative to keep the Ethernet I/O processing time to a minimum. Since all trainers (when active) are transmitting and receiving data, it is necessary to manage the transmissions in such a way so they are only sent to the trainers requiring them. As either WST instructor station must be able to command both WSTs in the MST mode, the network has the added requirement of supplying instructor control information to the slave station, as well as display information back to the controlling station. With some instructor inputs applying to only one trainer, a method of designating which trainer is being controlled must be implemented. An additional stipulation called for the simulation software on both WST's to be identical (i.e. both trainer's could be built from the same source code).

DESIGN APPROACH

The network addresses for each trainer are defined in an Ethernet initalization file which is executed upon computer initial program load. In addition to its own local address and a broadcast address, each trainer contains several multicast addresses within the network. These multicast addresses effectively create a subgroup of nodes for each training mode. With this implementaion, data is only sent to the trainers requiring it for their current mode, and only one transmission is needed to send the same information to several trainers.

For most software modules, it is inconsequential on which OFT or SOT they are being executed. For some modules, however, there are hardware constraints which require it to know physically, on which trainer it resides. For these modules, a trainer ID is assigned during trainer activation based on the local network address found in the Ethernet initialization file.

Trainer tasks within the same trainer load convey data to each other by means of a static memory partition, Datapool. To allow the separate trainer loads to communicate with each other, each trainer has its own designated Ethernet buffers within every trainer's Datapool. The Ethernet buffer configuration is the same in each trainer's Datapool and is illustrated in Figure 2. Each trainer can only write into its specific Ethernet buffer as the other buffers are continually overwritten by the Ethernet transfers from the other trainers.

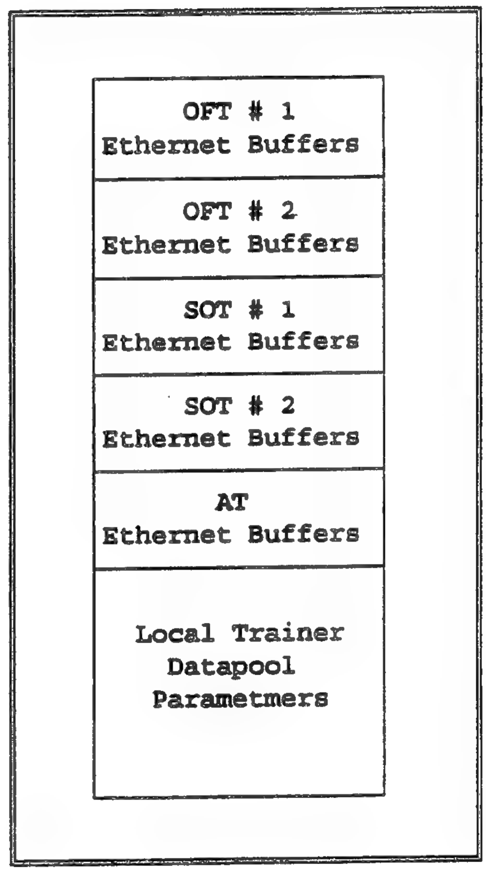

FIGURE 2. Datapool Layout

In order for software modules to be identical on both OFTs and both SOTs, yet keep the physical layout of the Ethernet buffers the same in all trainers, it becomes necessary for the Datapool dictionaries to be different on the two WST trainers. For example, the ownship aircraft's altitude mnemonic is FBALT and the other aircraft's altitude mnemonic is called FBALTB. On OFT #1, FBALT will reside in OFT #1's Ethernet buffer and FBALTB will reside in the

Ethernet buffer of OFT #2. On OFT #2, FBALT will reside in OFT #2's Ethernet buffer, while FBALTB will reside in the OFT #1 Ethernet buffer. As the Datapool source files must be the same, this organization of Ethernet buffers is accomplished when the Datapool dictionaries are built and again is determined by the local network address in the Ethernet initialization file.

To direct instructor control to each WST selectively from a single WST command station, a Helo A/B concept has been implemented. The trainer from which the scenario is being commanded is denoted as Helo A. The other WST is Helo B. A "Helo A/B Source Display" switch designates to which trainer the inputs will be directed and which WST values are being displayed.

Ethernet Protocol

A detailed description of the Ethernet protocol developed for this system can be found in reference [4], with only a basic overview of the system being provided here.

The Ethernet transfer packets are data chained Input/Output Command Lists (IOCL's). Each IOCL is six words in length and formulated as follows. The first two words contain a command to write a header which contains the multicast address, designating where the rest of the packet is to be sent. The next two words contain a command to write eight bytes of data from a local buffer. The last two words contain a command to write the number of bytes (X) from this trainer's Ethernet buffer in Datapool (BUFFER A). The local buffer specified in the second two words of the IOCL contains a read command to read X number of bytes into BUFFER A. By ensuring the physical address of Datapool is the same on all trainers, the receiving task then becomes a generic receiver for all transmissions from every trainer.

The Ethernet receiving task continuosly polls the Ethernet for incoming data by executing a six word data chained, wait I/O, IOCL. The IOCL is comprised as follows. The first two words contain the read command to read in the Ethernet header. The next two words contain the command to read eight bytes of data into the last two words of the IOCL, thereby making the last two words of the IOCL contain the read command generated by the transmitting trainer. This design greatly reduces any overhead that would otherwise be required to decipher from which trainer the data came in order to determine into what buffer to download the data.

The IOCLs executed by the transmitting module are initialized during trainer activation. Separate packets are constructed to specify the different multicast addresses for the available modes, as well as different buffer lengths, and the various buffer addresses. This enables the transmitting module to use the trainer mode, the trainer ID, and the current frame to execute the appropriate IOCL in order to direct the correct amount of data to the proper network address at the necessary rate while incurring the least amount of processing necessary on both the sending and receiving trainers.

As an example, the mode control information (trainer state, operating mode, and integrated mode change requests) must be transferred to all trainers in all modes. Also, it is more effecient for a trainer to transfer a complete buffer of data once rather than execute two transfers of varying lengths of the same buffer. In MST mode, some OFT data must be transferred at 30 Hz. By executing an IOCL specifying the broadcast address (all five trainers) on odd 30 HZ frames, and executing another IOCL specifying the MST multicast address (OFTs and SOTs only) on even 30 HZ frames, the mode control data going to the AT is still only sent at 15 HZ while the MST data is transferred at 30 HZ and only one transfer is required from the OFT. The resulting rates and destinations of buffer transfers for all trainers range from the simplest and least amount occuring when all trainers are in independent mode shown in Table 2 to the most complex and heaviest traffic of MST mode as outlined in Table 3.

Trainer Source	Transfer Size (bytes)	DESTINATION				
		OFT 1	OFT 2	SOT 1	SOT 2	AT
OFT 1	80		15Hz	15Hz	15Hz	15Hz
SOT 1	160	15Hz	15Hz		15Hz	15Hz
OFT 2	80	15Hz		15Hz	15Hz	15Hz
SOT 2	160	15Hz	15Hz	15Hz		15Hz
AT	64	15Hz	15Hz	15Hz	15Hz	

TABLE 2. Independent Mode Buffer Transfers

Trainer Source	Transfer Size (bytes)	DESTINATION				
		OFT 1	OFT 2	SOT 1	SOT 2	AT
OFT 1	1440		30Hz	30Hz	30Hz	15Hz
SOT 1	1440	15Hz	15Hz		15Hz	15Hz
	1440	5Hz	5Hz		5Hz	
	1440	5Hz	5Hz		5Hz	
	1440	5Hz	5Hz		5Hz	
OFT 2	1440	30Hz		30Hz	30Hz	15Hz
	1440	10Hz				
	1440	10Hz				
SOT 2	1440	15Hz	15Hz	15Hz		15Hz
	1440	5Hz	5Hz	5Hz		
	1440	5Hz	5Hz	5Hz		
	1440	5Hz	5Hz	5Hz		
	1440			10Hz		
	1440			10Hz		
AT	64	15Hz	15Hz	15Hz	15Hz	

TABLE 3. MST Mode Buffer Transfers (WST #1 In Command)

Instructor Station Protocol

The instructor station receives input from three devices: the keyboard, the trackball, and the digital inputs (DIs) on the instructor panel. The instructor station CRT displays are driven by CALCOMP Vistagraphic 4500 display processors (one per trainer). The display pages are pre-processed graphics code subroutines and are table driven for parameter updates and inputs. These tables contain information for every dynamic display entry on the page in order to determine what action to take when the item is selected, and how to format the display of the item's value. Display update is achieved by building a buffer of graphics code generated in accordance with these variable tables which, when downloaded to the display processor, overlays the current page, effectively updating the parameters displayed. Input for selected items is achieved by storing the new values into the variable addresses specified in the tables for those items.

Although only one WST instructor station is used in the MST mode, the instructor control software still runs in both trainers. The software modules providing the interface to the Helo-B instructor station hardware ignore any input from those devices. When the input from the command station is to be used by both trainers, it is processed as normal by the Helo-A instructor control software, but in addition, this software sends flags and control variables to the Helo-B station. If the input is specific to one trainer, the Helo A/B designator determines where the input is directed. If Helo-A is selected, the instructor control software in Helo-B does nothing, while the Helo-A software processes the input the same as in independent mode. When the "Helo-A/B Source Display" switch indicates Helo-B is selected the Helo-A instructor station interface modules send the input over the Ethernet, where the Helo-B modules process it as though it were generated by the Helo-B instructor devices.

The CRT displays for the Helo-B trainer are generated and updated in MST mode in the same manner as they are in any other mode. However, on the command station, when the "Helo-A/B Source Display" switch indicates Helo-B is selected, the CRTs must reflect the HELO-B values for the parameters displayed.

To preserve the table driven page design without having to add additional page variables for the Helo-B display, the stipulation that the trainer software be identical for both trainers was put to use. Controls were added to ensure both OFT trainers (as well as both SOTs) display the same CRT pages in MST mode. In this way, the item select information and data input, when sent over the Ethernet to Helo-B, can be processed by the page input module and loaded directly into the selected item's variable addresses as though it was entered from the Helo-B keyboard.

The restriction of guaranteeing both trainer CRTs display the same page in MST mode is also used for the display of Helo-B information. By adding handshaking controls between the Ethernet transmitting module and the display update routine, when Helo-B is selected, its graphic update buffer can be sent to the Helo-A page update module and downloaded to the Helo-A graphics processor, thereby redrawing the page parameters to reflect Helo-B values.

SUMMARY

The increased Ethernet traffic in the MST mode does heighten the number of deferred transfers and collisions. However, the only area where it proved critical was in the instructor control software. Fortunately, software measures could be implemented to protect the simulation in the areas where such occurences would be fatal. With the Ethernet protocol developed, the highest rate of transfers needed for the MST mode were permitted without degrading the simulation. The added feature of being able to use

one command station to control the entire scenario yet still control the WSTs individually results in a reduced instructor workload for a highly complex training scenario while still having full monitoring capabilities for both trainers. Through these technical modeling implementations, highly diversified capabilites have been made available in a single training system. The MST mode enhancements in the areas of communications, formation flight, and acoustic effects allow for coordinated ASW crew training in a common tactical problem world and still provide the high fidelity of simulation available in an independent mode.

ABOUT THE AUTHORS

Ms. Clinton has been employed by Reflectone since June of 1984. She holds a BSCS with Honors from the University of South Florida. Simulation projects within Reflectone include displays engineer for the AV-8B maintenance trainer and lead displays engineer on CV-HELO.

Dr. McCarthy joined Reflectone in March of 1981 after graduating from the University of Missouri-Columbia, receiving a Ph.D. in Condensed Matter Physics. Simulation programs within Reflectone have been primarily U.S. Navy ASW Helicopter Weapon System Trainers including the SH-2F, SH-3H, and SH-60F. Experience at Reflectone has been in the areas of Tactical Systems Engineering and Program Engineering leading to the current position of Director of Program Engineering, Military Programs.

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B-2 SIMULATOR ACQUISITION
THE ACQUISITION STRATEGY FOR THE 90s

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ABSTRACT

The dramatic increase in aircraft complexity, the high cost per hour to fly these complex aircraft, and continued resistance to low altitude military training require a major change in the development of aircrew training devices. No longer can the simulator serve as a procedural trainer; it must do much more. The question is how best to procure a trainer that does so.

Recently, there has been much written on the acquisition of weapon system trainers through the prime weapon system contractor. Aside from the increase in cost, this approach can preclude the acquisition element and the user from making direct inputs into the training system's development. This can result in the delivery of a very expensive, capability limited training system to the user. The associate contractor arrangement that CAE-Link has with Northrop on the B-2 program, combined with some innovative training development concepts, made the B-2 Aircrew Training Device (ATD) procurement the model for future training system acquisition. We in the B-2 program are in the process of building not only the most complex aircrew trainer yet, but at the same time, the best device for training crews. The complexity of the B-2 Bomber requires nothing less.

INTRODUCTION

The development of the B-2 Bomber presented both unique challenges and opportunities for the concurrent development of its ATDs. There are several theories as to the "best" strategy for simulator procurement, including acquisition through the prime, the newest approach to training system acquisition. The B-2 acquisition was the successful application of a traditional strategy aided by the ability to be more innovative because of the program environment. CAE-Link, Link Flight Simulation Division, won a separate competition to develop the ATDs. Aircraft data were provided to CAE-Link through an associate contractor agreement (ACA) with Northrop, the B-2 prime. Northrop also

is responsible for developing of the entire B-2 training program, to include all simulator courseware, primarily mission scenarios. The tie between Northrop and Link is important, for it is one of the keys to success of the B-2 ATDs. Although the Link contract is a government procurement, Northrop is fully responsible for the success of the B-2 training program, of which the ATD is the principal piece of hardware for aircrew training. This drives a close working relationship between the contractors, contributing to the government's ability to provide a quality training system.

There were three major programmatic challenges to the B-2 ATD acquisition to be overcome. First and foremost, the user, the Strategic Air Command, required an operational ATD be in place and ready for training (RFT) prior to delivery of the first operational aircraft to Whiteman AFB, MO. The ATD had to identically match the delivered aircraft, the second major challenge. The third challenge was developing the ATD at the same time as the aircraft. Handling the massive influx of changes as the aircraft developed required some very innovative techniques in engineering, contracts, and management.

Two independent factors combined to make the meeting of these challenges a success story in the arena of concurrent simulator development. The B-2 Program Management Directive (PMD) called for a streamlined management approach to the entire B-2 acquisition. The high level of security at the start of the program kept the B-2 team small. For example, the B-2 Air Staff representatives reported directly to the Secretary of the Air Force. Streamlined management drove flexibility, while security drove small team size, a great combination for innovative acquisition.

It is important to note that during the building and execution of the acquisition strategy, all acquisition guidelines and regulations were followed to the letter. Our advantage was that our decisions were reviewed by higher levels of management that were new to training acquisition. They trusted the judgement of the ATD team, and that trust allowed the implementation of many of our innovations. The small acquisition team also aided in that many of the upper-level decisions were delegated to the B-2 core team, dramatically reducing the number of individuals involved in the decision making process.

One other factor contributed to the innovations that we were able to use. Because cutting-edge technologies such as those used to develop the B-2 ATD pose greater risk, the Full Scale Development (FSD) portion of the contract was a cost plus incentive fee with award fee arrangement. This is

a controversial approach, the foremost objection being that it virtually guarantees cost growth will occur on the program. This has happened to a limited degree in the B-2 ATD acquisition. The philosophical question is whether the predicted and planned for cost growth is worth the value to the B-2 program as a whole. The importance of the simulator to the B-2 is such that "yes" is the only answer. The high cost of the program plus the unusually cooperative environment made some of our innovations a little easier to implement, but these innovations would work on a more common Firm Fixed Price (FFP) arrangement. Other programs can take advantage of all of the things the B-2 ATD has done.

INNOVATIONS:
Managed Through the Aircraft SPO

As mentioned, the classified nature of the program allowed many avenues to be explored in simulator acquisition. However, many of the innovations can be transferred to more traditional acquisition. The single, greatest advantage that our "black" existence gave us was management under the auspices of the B-2 System Program Office (SPO). The majority of the training systems procured in the Air Force are bought through the Training System SPO. The movement of the B-2 ATD acquisition to the aircraft SPO allowed a much closer working relationship with the aircraft developers.

With concurrent development of the aircraft and the ATD being the single greatest challenge to the program, the advantage of co-location made for better communications in the area of aircraft change. Every aircraft engineering change proposal (ECP) was reviewed for its impact on training. That impact was thoroughly briefed to the configuration control board (CCB) and the training costs included in the budgeting for the overall ECP costs. This improved engineering communications has returned a major dividend to the entire B-2 program. The first ATD was designed to match the first aircraft delivered to SAC, SAC-1. As is normal in any major aircraft development, the engineering community looked at the next aircraft off the production line and focused the majority of their effort on that aircraft. The ATD development toward SAC-1 worked as a background "sanity check" to ensure that short-term solutions did not adversely affect the B-2 aircraft in the long run. Already, several potential problems have been averted due to this mechanism. For example, the original avionics control unit (ACU) computer complex on the aircraft required some modification. Northrop's original solution would have improved the air vehicle and saved money, but the impact to the ATDs was considerable and actually surpassed any savings made on the aircraft. Northrop called Link in and the two companies along with the SPO came up with a

solution that fixed the problem and saved money on both programs.

Another major advantage has been the ease of access to SPO engineers working the aircraft subsystems. From the beginning, these engineers were educated on the team approach to the B-2 development and how critical the success of the training program was to the success of the entire program. With this in mind, there has been little difficulty in gaining participation from engineers to support ATD development, up to and including trips to the Link facilities to better explain subsystem operations to Link engineers. Both SPO and Link engineers benefitted greatly from this interface.

The final major advantage of being under the wing of the aircraft SPO is funding. Being funded as a weapons system package with the ATDs being part of the entire system was a great advantage. As will be explained later, maintenance of concurrency is expensive. The parallel development of the ATD with the aircraft in the FSD portion of the program created the potential for some very large "Unknown-Unknowns." The traditional simulator funding profile would not be able to support the management reserve required to adequately cover the program in this area because of the large number of changes in the aircraft. With the ATD being covered by the management reserve of the aircraft budget these problems were overcome. The cost of the ATD program is a very small percentage of the total B-2 program costs, and this allows for some flexibility in financing.

INNOVATIONS

The Link-Northrop Connection

Another major plus for the success of the B-2 ATD was the excellent relationship that developed between the prime aircraft contractor, Northrop, and Link's Flight Simulation Division. Initially, Northrop established a boilerplate ACA with all the contractors bidding on the B-2 ATD project. After contract award, Link tailored this arrangement to maintain the flow of data from Northrop. Establishment of an ACA was not an easy task. Working out the details for a smooth flow of aircraft data to Link took a great deal of time and effort. This ACA continues to change as requirements evolve. Currently an amendment to the ACA is in progress to allow Northrop instructors to be trained in ATD operation. This type of flexibility in the ACA is a requirement for success. As a result of this ACA, a solid commitment from Northrop was realized with the establishment of a group of five employees whose sole purpose is to provide and track the data Link needs to build their

simulator. In addition to this group, four Link employees are co-located with the Northrop team to assist in data collection, interpretation, and transfer. The Link group's initial charter was to identify to Northrop the information required by the simulator engineers.

As the aircraft matured, the members of this group became involved in the earliest phases of the aircraft change process. Link now receives preliminary word of upcoming changes very early in the Northrop change process. This alone has saved the program large sums of dollars by postponing work that was to change. Northrop, with its responsibility for total training, also uses this ATD team to better integrate the simulator with the rest of the training system. The positive working relationship of this group has been a major contributor to the success of the B-2 ATD development effort.

INNOVATIONS
Concurrency

Since the introduction of simulators modeled after specific aircraft, the greatest challenge to the simulator industry has been to accurately mirror the aircraft in a timely fashion. The B-2 ATD has had the commitment of the SPO Director that the delivered ATD will be the same as the delivered aircraft. This solid support from the front office allowed us the opportunity to do some innovative things from a contractual viewpoint. First, all significant (Class One) changes to the aircraft that affect the simulator automatically become Class One changes to the simulator at the same time. The reason for this is that B-2 SPO management has signed up to include funds in aircraft ECPs to make Class One changes to the simulator.

We also developed a novel method for handling smaller (Class Two) changes. In traditional procurement management, small changes are accumulated over a period of time and incorporated into the simulator through block updates. With our commitment to concurrency and the heads up we receive from the ATD team at Northrop on aircraft changes, we approached change differently. Our contract authorized Link to make all aircraft-driven changes to the simulator. Changes that cost less than $25,000 were made without government notification. Changes above that threshold were submitted to the SPO. These changes would also be implemented unless the SPO gave guidance otherwise. Approval was granted by the ATD program manager after review by the SPO ATD team for all but one of the submitted changes. This process was in place through system Critical Design Review (CDR) and accounted for 109 changes to the simulator of which only seventeen were above the $25,000

threshold. It helped keep the ATD concurrent with the aircraft and prevented millions of dollars being spent on ECP preparation and rework for changes that would have been automatically approved anyway. After the period of performance, the cost for these changes was submitted to the government, which had been tracking and budgeting for these changes. A similar program has been developed to manage change after system CDR.

In addition to managing real time changes, an engineering effort was put forth to handle future concurrency issues. The B-2 bomber is an incredibly software intensive weapon system. Because of the size of the software effort it was obvious from the beginning that there would be large numbers of software changes. Again, as with hardware changes, the current philosophy is to hold these changes until a block update is economically possible. We have overcome this problem by designing the ATD to run on the same software that is used in the aircraft. By doing this, a software change to the aircraft can simultaneously be made to the simulator with identical results. Our only shortfall in this area is that we are entirely dependent on aircraft software development in order to allow the ATD to "fly" like the aircraft, and this has caused some perturbations in the ATD schedule during aircraft development. This drawback was recognized in the original acquisition strategy, when the decision was made to accept simulator schedule impacts to allow for a concurrent machine. Additionally, this was one of the drivers to the cost plus contract.

INNOVATIONS
Operations and Training Analysis Group
(OTAG)

The B-2 Bomber is an extremely complex weapon system. Early in its development it became apparent that the training device had to offer a degree of fidelity and training capability that was beyond any device yet developed. Two new groups were developed to make this happen, the Operations and Training Analysis Group (OTAG) and the Training Systems Working Group (TSWG). OTAG is an organization of Link employees who are former military aircrew instructors. This group is represented at all major company meetings, both engineering and management, and is crucial in assessing the training impact of all changes to the simulator. In addition to assessing training impacts of engineering changes, OTAG members bridge the gap between simulator specifications and training needs. They do this by serving as a kind of surrogate user, putting themselves in the position of both student and instructor. However, they are not an independent team; their objective is to put themselves in the place of the user. In this capacity, they

also assist engineering and test by being the crewmember during developmental testing and contractor mission testing (to be explained next). Building a simulator to replicate the aircraft is a simpler job than building a simulator that also meets the needs of a rigorous training program. OTAG's greatest responsibility is to maintain the "training first" baseline of the program.

INNOVATIONS
Training Systems Working Group (TSWG)

While the engineering process yields a simulator, by itself it does not yield a training device. TSWG was established to ensure that a well designed simulator becomes an even better training device. To ensure that the high degree of training was met, the TSWG was formed in the beginning stages of the ATD's development. This team was composed of members from SAC, the SPO, Link, and Northrop. These four groups contributed aircrew talent from all four services and commercial airlines, with a total of more than 100,000 hours of flying time, half of which was instructor time. From this core of experience the training capability of the B-2 ATD was formed. The majority of their work was accomplished prior to system CDR, but the group can be called at any time to resolve training issues that continue to surface. For example, all of the pages for the instructor panel were finalized prior to CDR. The work done by the TSWG revolved around two major areas: simulator fidelity and training performance. At all times, training benefits were weighed against program costs. To give an example, the idea of giving the instructor on the right seat trainer his own radar tracking handle was raised. After discussing the low utility of this in the FB111 Bomb Nav Trainer, the concept was rejected. On the positive side, the design of the state-of-the-art instructor console came out of this group. This panel will allow changes in the mission scenario to be made quickly and effectively. The instructor can spend far more time as an instructor and less time as a simulator operator. The TSWG is one of several innovative groups used on this program that has kept the B-2 ATD from becoming just another simulator. Going into this development, training was the overriding theme in all aspects. The TSWG went a long way in ensuring this philosophy was retained.

INNOVATIONS
Operational-Based Testing

The importance of training even reaches the test area of the B-2 ATD acquisition. Traditional government simulator testing consists of detailed testing of each item in the specification, at times taking months. Often results of this type of testing were strained relationships among user,

SPO, and contractor, a very large stack of test discrepancies, and a simulator in which training was perceived to be a secondary function.

The B-2 ATD test approach de-emphasizes the importance of specification testing. Instead of the traditional test, an operational testing program was developed, its basic premise: test the capability to train. There is a developmental test and evaluation (DT&E) period of about four weeks, during which stand-alone systems and subsystems are thoroughly tested (to specification requirements). These systems include things such as the motion base, image generation system, and digital radar landmass simulation (DRLMS). After successful completion of DT&E, operational test and evaluation (OT&E) is started. The TSWG participants identified what needed to be trained in the simulator both from an initial instruction and a continuation training perspective. The operational test plan was built around these requirements for training. Each training function would be accomplished in the simulator: how it performed the function as compared to a predetermined threshold determined the success of the test. To make this a smooth operation, a copy of the operational test plan is given to the contractor, who runs all the tests prior to calling in the Air Force to run the government testing. The contractor's mission test is performed by OTAG. If this group does a thorough job, the government OT&E will be complete in the five weeks scheduled. Although important, this type of testing is not conducive to the total training solution.

Even test discrepancies (TDs) are based on training. All TDs are written and prioritized by their impact on training. The priority of these discrepancies ranges from stopping a test to items that can wait for reassembly at Whiteman AFB. However, the test methodology, with the contractor doing its mission test, should significantly limit the number of TDs. This test approach is a major departure from the past that can pay big dividends in the future.

INNOVATIONS

Things That Didn't Work

With all the things that were tried on this program that were a success we did have some failures. Holding onto the belief that the first delivered ATD would have total aircraft capability caused some problems. We thought that our innovations would allow this to occur. If we had created a phased approach at the beginning, we may have saved some time and money. We learned that, no matter how creative you may be, there is always gravity.

CONCLUSIONS

Much innovative thought went into the development of the B-2 ATD. This was a necessity. The challenges of the program required a different approach to simulator acquisition in order to get the job done. Have we been successful? As of this writing the schedule shows a delivered ATD with the same training capability as the aircraft, prior to that aircraft's arrival. Not everything we tried will work on all trainer acquisitions, but we hope that this paper will stimulate thought on alternative acquisition strategies for other systems.

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THERE MUST BE A BETTER WAY TO TRAIN: THE APPLICATION OF UNRESTRICTED REAL-TIME PRACTICE TO LOW COST TRAINING SYSTEMS

Michael E. Naber and Dorothy T. Stone

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ABSTRACT

"Learning by doing", often by trial and error, was one of the earliest methods of transferring knowledge, and it is still one of the best. Children learn from their parents, by experimenting and attempting to duplicate their actions, and by receiving constructive feedback on their performance. Early computer-based training systems did not allow students to practice behaviors, and consequently did not achieve the transfer of training benefit that experiential learning affords. Full fidelity simulators do provide the opportunity for unrestricted practice in a realistic environment, but at a cost that often prohibits their widespread use. The solution to this training dilemma is functional simulation of a complex system, run in real time on small, portable, inexpensive computers.

The Fuel System Simulator is a current application of this approach. It uses a combination of tutorials, guided practice, interactive freeplay and automated performance assessment to solve a real-world aviation maintenance training problem. With a design that adapts easily to many training tasks, the FSS approach encourages heuristic learning, resulting in a high level of student performance. It provides the optimal level of fidelity, balancing training goals and affordability. In today's cost-constrained environment, this type of trainer provides an attractive alternative to full fidelity simulators or traditional CBT.

INTRODUCTION

The simple experiences of childhood are often the ones we remember the longest. Memories of burned fingers when we first tried to use the toaster, for example, remain with us far longer than the repeated admonitions of our well-meaning parents. The things we learned long ago, many of them the hard way, came in the form of simple but powerful lessons. We learned because we did something, and then saw the immediate consequences of our actions. Those principles are as valid for our training today as they were then.

Historically, training really started "on-the-job". In very early days, children learned from their parents, often by trial and error, the things they needed to know to survive. Parents were the models who shared their knowledge and expertise. Children attempted to duplicate their parents' actions, and were given feedback and corrective advice. Their learning was based on repetition, practice and the development of psychomotor skills. This was one of the earliest methods of transferring knowledge, and it's still one of the best. As humanity became more organized and sophisticated, no one person could know all there was to know. Consequently, specialization occurred, and along with it came teachers and stand-up training. As societies developed, life grew even more complicated. People had to be taught how to use machines, how to communicate in other languages, and how to do things better and faster. Textbooks and lectures became common instructional methods, and the demands for teachers and training increased exponentially.

Eventually, analog and digital computers appeared on the scene. Their invention meant that procedural training could be supported by automated training devices; that a computer would do some of the functions normally performed by a teacher. The result was the emergence of a whole new discipline - - computer-based training (CBT). With the advent of computers and CBT, technology-based training enhancements could also be explored. Authoring systems were developed to support uniformity and increase student throughput. Colorful computer graphics and "user friendly" input devices were incorporated to add interest and promote interactivity. All of these advances had benefits, but they also shared a major problem. They did not allow for the "what if I do this?" scenario, i.e., unrestrained experimentation and practice to see what will happen. The value of "learning by doing" was not being captured.

ENCOURAGING TRANSFER OF LEARNING

The incorporation of simulation into CBT occurred because training professionals realized that an important learning component, the ability to practice actual tasks, was missing from existing training devices. Computer-based simulations were developed for a wide variety of sophisticated systems. Inevitably, the more complex the training task, the more complicated the training device, and the simulation, became. Fidelity (i.e., how "realistic" is it?) became one of the key goals for this new medium. It was believed that high fidelity (and consequently high cost) would ensure true learning.

Each of us involved in training has wondered "is my training going to make a difference?" "Will the learning transfer to the real world?" "Will the trainees actually make changes that will improve performance, or is the training just another break from the daily routine?" Research has shown that **practice** combined with **feedback** on performance produces a very high level of learning transfer.[1] Training professionals currently working in the field agree. In a recent article in Training magazine, Dr. Jack Asgar, states:

> "If you expect trainees to apply what you are teaching them back on the job, design learning activities that require them to use the same behavior they must use in real life."[2]

SIMULATION AS A TRAINING SOLUTION

Determining the best training approach for a particular system or piece of equipment means evaluating alternatives against a number of goals. Along with the training goals, we also have to consider access and availability, technical issues, system life expectancy, safety, supportability and, of course, cost. As an example, Table 1 illustrates three options for training an operator to use a piece of equipment in a cockpit, in this case a fuel control panel. The options all offer a high degree of functional fidelity, but with varying cost, interface, and revision considerations.

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[1] Bond, Cdr Jeffrey P., Royal Navy Directorate of Naval Education and Training Support: "Computer Based Training - Hit Or Myth", Proceedings of the 10th Interservice/Industry Training Systems Conference, December 1988.

[2] Asgar, Jack: "Give Me Relevance or Give Me Nothing", Training, July 1990, p. 50.

Table 1-1. Tradeoff Analysis of Equipment Training Options

PANEL OPTIONS	FIDELITY	COST	INTERFACE	UPDATE
Actual Panel	Tactile - High Visual - High Functional - High	High	Possibly Complex	May Be Time Consuming
Emulated Panel (3-D Mockup)	Tactile - High Visual - High Functional - High	Medium High	Less Complex	May Be Time Consuming
Interactive Graphic Representation	Tactile - Low Visual - Moderate Functional - High	Low	Minimal Complexity	Easily Done

Unfortunately, in aviation, be it military or commercial, we can not often give trainees the opportunity to practice in real time on real equipment. It is far too costly for many training applications, and the consequences of mistakes can be catastrophic. For these high risk/high cost applications, simulation has become widely accepted as the preferred way to train. Unfortunately, even simulators have their limitations, as we try to meet widespread training needs with a few very expensive resources. In the attempt to achieve ultimate fidelity, the industry has created trainers that are too expensive for widespread use. The solution to this dilemma is functional simulation of a complex system, run in real time on small, portable, inexpensive computers.

A BETTER WAY TO TRAIN

This solution has proven to be particularly effective in the training of discrete, specialized systems, i.e., when there is a specific training problem. Within the aviation field alone there are a number of specialized systems which must be understood and mastered. Complex new navigation systems, for example, require the aircrew to follow correct procedures and make appropriate navigation decisions. Maintenance systems are also well suited to this technique.

The Fuel System Simulator (FSS) is a maintenance application of this approach, developed in response to a real world problem. The FSS is a powerful, low cost training tool that goes "back to basics", using learning-by-doing training concepts, but implementing them with state-of-the art simulation technology. It trains airline maintenance personnel to perform fueling, defueling, and fuel system troubleshooting on the DC-8 aircraft. It combines self-paced tutorial lessons and guided instruction with unrestricted, real-time practice -- interactive freeplay. With its dynamic fuel system simulation and interactive fuel panel representations, it essentially "brings the aircraft equipment to the student". The simulation concept for this particular trainer is threefold. Functional simulations of the Fuel System Control Panel, important Subsystem Operations, and Fuel System Schematics are combined and correlated in a single training system that resides on a desktop PC. By concentrating on functional fidelity, the FSS simulates those things which are critical to achievement of the training goals, but in a way that is also affordable.

The training system is comprised of four training modules and an optional authoring module.

The Controls and Displays Module is a tutorial that presents a detailed graphic representation of the fuel panel. Using the touchscreen, students can "explore" the panel by selecting a switch or gauge and then seeing a text window that explains the function and operation of the selected item.

The Schematics Module is also a tutorial, and it provides color-coded and labeled schematic diagrams of pertinent systems and subsystems. Trainees can randomly select any schematic for viewing and can compare the schematics of the two different DC-8 airframes.

The Demonstration Module gives students added understanding and guided practice in basic fuel system operations. As they make fuel panel selections or perform other fueling tasks, the trainer graphically displays the consequences of their actions.

The Freeplay Module gives trainees the opportunity to "put it all together". Using exercises created by a knowledgeable instructor, students work with a fully functional fuel system simulation to perform fueling or defueling procedures or to diagnose and correct problems. Trainees can identify and select components to change, test, or repair, and can perform any procedure they wish in any order. In short, they can operate just as they would "on the job", but the costs of an error, or the practice itself, have been eliminated. The Freeplay Module also automatically tracks and records student actions for future performance assessment. At the end of an exercise, trainees can see a summary of their actions and evaluate their performance against that of an expert. Instructors can review student performance at their convenience by recalling the desired student file.

This set of capabilities has traditionally been available only in large, high fidelity trainers or through real-life experience on the job. The FSS combines the benefits of simulation with the advantages of random access to information, so that students can select what they wish to learn and can progress at their own pace. Its small size, portability and low cost means that systems can now be located at remote sites, minimizing productivity losses, strain on centralized training facilities, and the costs of bringing students to them. It runs on general purpose hardware, so that dedicated equipment is not necessary. The system can be used as an integral part of a larger training program, or can serve as a performance support system, providing "just in time" training on the job.

The FSS design has several key features which contribute to the system's versatility and effectiveness. Its flexible architecture makes it very adaptable. The approach can be applied to other avionic systems, to other maintenance functions, or to other training problems. Since retention of learning is improved through interest, the design features a high degree of interactivity, coupled with a "user friendly" touchscreen interface and extensive "HELP" system. The complete and accurate simulation of the fuel system prevents negative training, since functional fidelity is very high. The variety and "what if" capability it provides also adds interest and encourages heuristic learning by allowing unrestricted practice and then providing corrective advice. The approach is both effective and efficient, since it results in a high level of student performance at a very reasonable cost.[3]

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[3] Kearsley, Greg, "Instructional Technology and Worker Learning Needs," report prepared for the Office of Technology Assessment under contract No. L3-5615, February 1990.

CONCLUSION

Desert Storm proved that training must be a primary goal of military organizations around the world. In today's cost constrained environment, however, the prudent training manager will look to systems that are not only cheaper, but also faster, smaller and, in many instances, better than their predecessors. These new systems take advantage of technology, but also provide the optimal level of fidelity so that students can "learn by doing" at an affordable cost. Some of their improvements come as a result of enhanced capabilities of commercially available hardware - - multi-purpose hardware that can host a variety of applications. Others are achieved through the application of tools which yield development efficiencies. The greatest cost and training benefits are realized, however, when these factors are merged with effective real-time simulations of complex systems. Companies with the skill and technical expertise to do this well can provide very attractive training alternatives to high fidelity simulators or more traditional CBT.

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PACEXTRA: Decision-Making Training Through Computer-Based Exercises

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I. PROBLEM

The process of making good decisions, on any job, is a complex mixture of setting goals, collecting information, defining alternatives, weighing options, and choosing solutions. While rules, guidelines and procedures can be established to aid in this process for a particular job, and training for the job can explain and even demonstrate proper application of these, trainees seldom reach uniform proficiency in decision-making. Decision-making proficiency is a function of knowledge, skills, and rules acquired through varying operational experiences. In this case, an attempt was made to focus on the knowledge and decision-making acquired through "in-vivo" experimental training, (Rasmusson 1986) as opposed to rule or skill based decision making.

The Pacific Air Forces (PACAF) Crisis Action System (CAS) is formed only during times of crisis or exercise. The job of Executive Officer for the CAS is one of assisting the CAS Director in managing the CAS and its staff of up to 40 or 50 people. The primary CAS Exec duty is to screen all incoming correspondence (a majority of which are messages) to determine what action, if any, is required of the CAS; to assign that action to one or more staff members; and to track the progress of that action to its completion, as other related and sometimes overriding events occur.

The job of PACAF CAS Exec is filled by officers assigned to the Directorate of Command and Control (DOC) under the Deputy Chief of Staff for Operations (DO). There is a requirement for several people to be available for multiple 12-hour CAS shifts, which are combined with other normal duty commitments, and are subject to typical reassignment rotations. This creates the need for ongoing training of new CAS Execs. This, in turn, demands on-the-job experience which previously would only be gained during actual crises or large scale exercises.

II. APPROACH

Overview

The approach taken to experimentally address the problem of providing CAS Exec trainees with realistic job-like experience has been to employ state-of-the-art off-the-shelf microcomputer software and hardware to develop individualized job-like exercises. Apple Macintosh computers were chosen as the training environment due to their ready availability in the command center. The exercises place CAS Exec trainees in a full-color graphic environment, replicating the PACAF CAS. A scenario of realistic crisis-related events is presented. (See Figure 1). The trainee is expected to judge the significance of each event, and if CAS Exec action is appropriate, to make that decision and take action using on-screen tools. These tools replicate real-life means of decision execution. They include the means for making phone calls, sending messages, tasking staff members, taking notes, logging events, tracking suspenses, using references, and compiling situation reports (SITREPs). See Figure 2. The trainee can also obtain advice and feedback on the appropriate actions for each event. (See Figure 3.) This is available at varied expertise levels, depending on trainee experience and training need.

The training system, called PACEXTRA (for PACAF CAS EXec TRAining) also incorporates an interactive authoring system which allows Subject Matter Experts (SMEs) to create and refine training exercises. This system facilitates the creation of individualized exercises, composed of a chain of custom events, through a graphic interface, which requires no programming and minimum training.

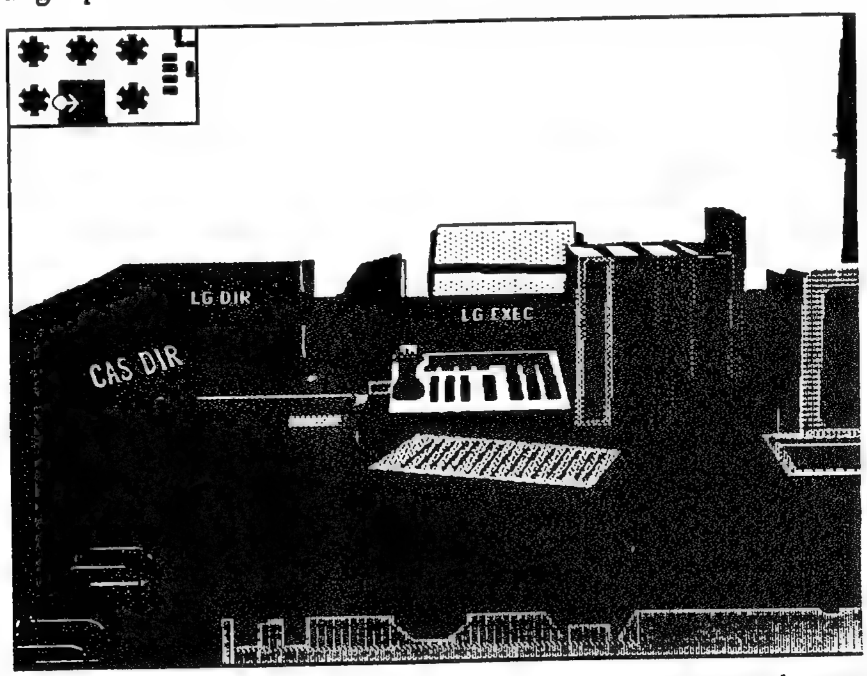

Figure 1. PACEXTRA puts CAS Exec trainees in a graphic environment representative of the actual PACAF Crisis Action System. (Note: The quality and content of the actual screen display was degraded significantly in de-colorizing it for this printing.)

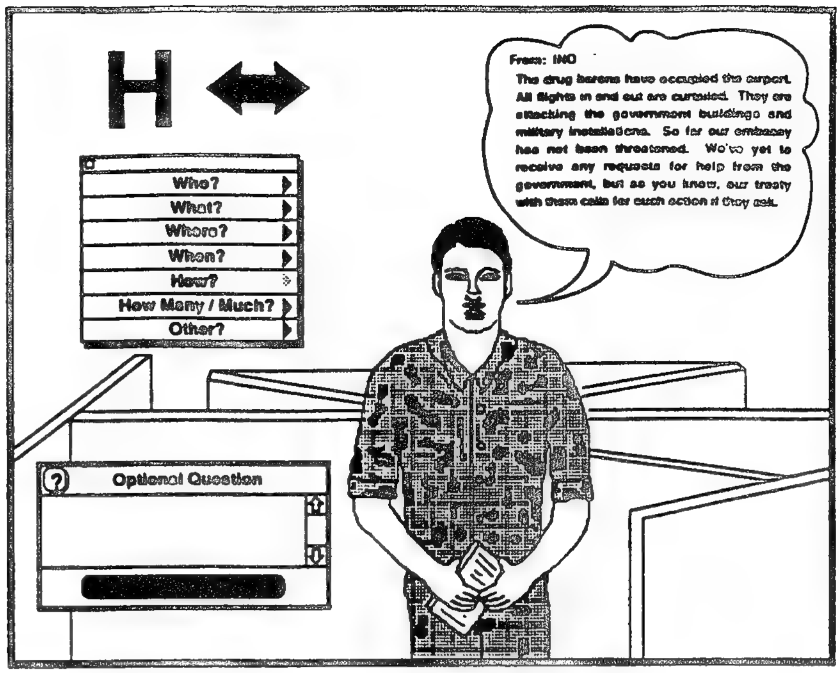

Figure 2. Trainees interact with simulated CAS staff members through graphic screens which incorporate two-way textual conversations. (Note: The quality and content of the actual screen display was degraded significantly in de-colorizing it for this printing.)

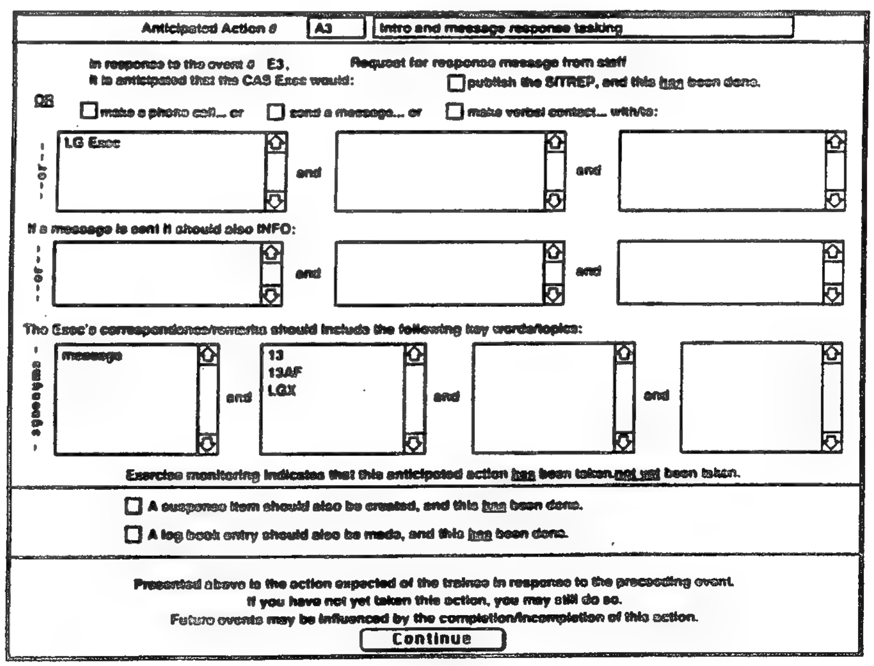

Figure 3. When a trainee reviews advice and feedback, it is through a display listing the type, recipients, and content of his anticipated communication.

Design

The design process for PACEXTRA was three-phased, consistent with the three major components of the system. First, the exercise system was designed, then the authoring system, and finally the lessons. All design was constrained by the chosen hardware and software.

Design of the Exercise System

The goal for the Exercise System was to have it replicate, as realistically as possible, the environment in which the CAS Exec performed his/her job in order to provide "real" experience in the events that he/she would encounter. The desk and related locations and items in the CAS "Ballroom" were provided graphically. This "ballroom" contains seven desk groupings, five of which are hexagonal cluster units. The other two are a set of four administrative area desks, and a modified "U" shaped desk set at which the directors and executive officers sit, all of which are represented on the PACEXTRA screen.

It was decided to use "Super 3D" software to create a three-dimensional electronic, colored model of the complete ballroom complex, including furniture and pertinent equipment, with varied level of detail. Electronic "snapshots" of any point in the room could then be taken from any eye point and at any range. Realistic perspective views from the Exec's desk (including phone, books, in-basket, terminal, etc.), as well as any location in the room that is pertinent to a decision being made, were thus provided.

To present and control these views, and the variety of event-related items, it was decided to use the windows, fields, buttons, and graphic objects inherent to SuperCard. Thus, exercise characters, their words in cartoon-like bubbles, messages, phone conversations, book pages, etc. would all be developed as overlaying objects, with the scene itself in the SuperCard "background". This approach would be efficient to implement, and make it relatively easy to make modifications as the system matured and was tested. The standard 640 X 480 pixel Macintosh screen was chosen so that the exercises could be run on any Macintosh II hardware with sufficient memory and speed. It was decided that on-line aids would be provided to introduce trainees to PACEXTRA.

Design of the Authoring System

The goal of the PACEXTRA authoring system is to make it possible for those personnel supervising the training for the CAS Exec job to create and modify exercises with only an hour or two of training on the use of PACEXTRA. Since the heart of an exercise is the events and subsequent trainee actions, it was decided that the authoring process would center around a graphic "chain of events". The chain is on multiple screen "pages" and is created by linking graphic icons representing different event types and anticipated actions, each one labeled with its identifier, name, and source. (See Figure 4.) "Double clicking" individual icons on the chain will then take the author to the same screen that the trainee will eventually see when that event occurred. The author can then add all the details (in text form) required to make it a true

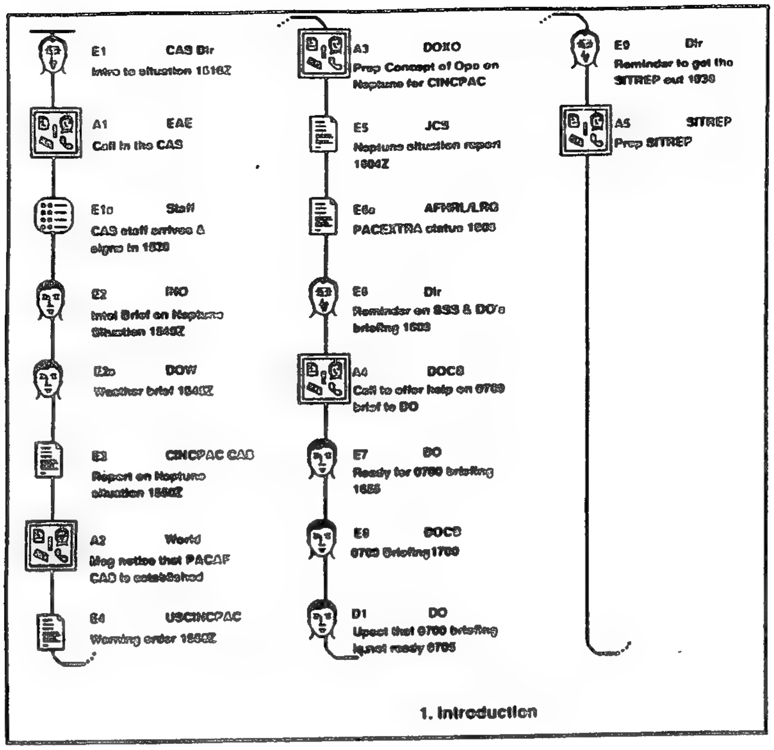

Figure 4. The author works with a graphic chain of events representing the sequencing of the exercise and providing access to the details of each event or anticipated action.

event, together with required behind-the-scenes administrative details. The means of making some events dependent upon previous trainee actions is included here, thus giving exercises a branched feature. In addition, it is possible to define questions which the trainee may ask of event characters and the possible responses the system will give.

In order to provide a realistic set of people within the CAS with whom the Exec interacts, a supporting "cast of characters" authoring process was created. The author combines faces and bodies (in Battle Dress Uniforms (BDU) or flight suits) and assigns each to an agency and a desk in the ballroom. Thus, a broad cross section of rank, race, and sex, can be used to staff the CAS with a different group of people for each exercise. This approach permits an author to change or move agencies so as to remain current with the changing real CAS makeup, as well as provide a more interesting milieu in which the student performs the CAS Exec duties. An on-line authoring aid was designed so that exercise authors could learn about the authoring process while on the system. This, and the guide for trainees, is available in printed guide separate from this report.

Design of the Exercises

Design of the first of two exercises involved meetings with PACAF DOC and DOX staff members. It was decided that the subject would be an insurrection in a fictitious island-country called Neptune. The events and actions would involve setting up a Joint Task Force (JTF) and supporting the JTF with fighters, tankers, troops, supplies, equipment and airlift. The second exercise focuses on orienting the new Exec to the CAS, through events involving the staff. This tests the application of this system to a slightly different form of training than the crisis action experience itself. (In practice, the trainee ideally goes through the orientation exercise first, followed by the Neptune exercise.)

The exercise design process begins with the development of a "short story" on paper. (It is important to note here that this first step is not a storyboard, but rather just a skeletal narrative of the events and actions planned. A storyboard is inappropriate because the subsequent authoring process will create displays which automatically consist of chosen ballroom scenes, people and text. To pre-sketch them would be wasteful and counter productive. It could be said that the on-system authoring process automatically creates a storyboard as the first draft of the exercise.) Once the story is developed, the cast of characters is created on the system and events are sequenced on the on-screen chain. Finally, the details which reflect the "short story" are added. Thus, the exercise design and development process become one, once the story is drafted.

Development

The PACEXTRA development process consisted of five major steps.

1. Collection of subject matter details
2. Producing the required graphics
3. Developing the supporting software
4. Authoring the exercises
5. Testing, refining and reporting the system

Each of these is addressed on the following pages.

Collecting Subject Matter Details

Information on the CAS Exec's job, the tools he/she employs, and the environment in which he/she works was obtained through visits to PACAF/DOC. Unclassified documents and forms were collected, measurements and photos were taken of the ballroom, and discussions were conducted with staff members, particularly with those already qualified for CAS Exec duty. As the system matured, it underwent an informal formative evaluation by these people.

Producing the Required Graphics

Photos and measurements taken of the ballroom and its equipment were used to electronically model the principal CAS physical components to scale using Super 3D software. This included the desks, chairs, printers and large screen displays throughout most of the room, in a moderate level of detail. At the Exec's desk, detail was taken to a more refined level, including the individual phone buttons and the binder rings on clipboards and notebooks. Then electronic "snapshots" were taken of Super 3D ballroom screens, set up to represent the Exec's line of sight while seated at the desk, while turned to talk to the Director, while turned to talk to visitors, while approaching each desk cluster, and while approaching an individual cluster desk position. Capture (TM) software was used to take the electronic snapshots which were in turn imported into the SuperCard environment as card backgrounds.

Super 3D was also used to create enlarged views of the Exec's tools, such as the telephone receiver, opened and closed notebooks, message clipboards, computer terminal, etc. These were captured and imported into SuperCard as graphic objects. The graphic functions built into SuperCard were used to modify and embellish these items and to create other items such as the cartoon-like bubbles used to enclose the words spoken by scenario characters.

To support the process of creating a cast of characters, a graphic artist drew monochrome faces and bodies using Super Paint. These were imported to SuperCard where they were sized, colored, and refined so as to create a library of some 24 faces and 12 bodies. These include male, female, black, white, officer (Major), enlisted (MSgt.), BDU and flight suit. The author has access to these on pallets while using the "Casting of Characters" feature.

The drawing and painting feature of SuperCard (in some cases aided by Super 3D) were used to create the remaining graphics. These include the icons and background for the event chain, large "Help", "Stop" and "Next/Past Event" buttons for the trainee, and other items on behind-the-scenes authoring screens. SuperCard's buttons and fields were used extensively in this area.

Developing the Supporting Software

As explained previously, a great deal of the development of PACEXTRA involved using the non-programming features of Supercard to create windows and cards, to draw and paint graphics, and to define and insert buttons and fields. However, these hypermedia functions alone are only a portion of PACEXTRA. To make the system perform as it does, a significant amount of software code (Supercard script) was written. Approximately 1,000 hours of programmer's time was required for this.

Due to the object-oriented nature of SuperCard, the unique PACEXTRA code (script) is contained in the various system objects including projects, windows, backgrounds, cards, fields, buttons, and graphic objects. PACEXTRA Software Document (separate from this report) describes the software scheme in some detail. The script itself is accessible within PACEXTRA through SuperCard and its subsystem, SuperEdit.

Authoring the Exercises

The two exercises were developed by first outlining a series of events on paper (in much the way a short story might be outlined). A cast of characters was then developed with which to staff the CAS. A chain of events and anticipated actions (responses by trainees) was developed on the system, and details were added to each event and action. These details included the text of messages, phone calls, and direct contact with CAS characters. They also included the definition of any conditions (trainee actions) which are to influence the occurrence of specific events. The result of this process, and the reviews and refinements which followed, are the two exercises delivered with PACEXTRA.

The scope of this project did not allow for formal testing of PACEXTRA. Testing has been limited to that done by Logicon during development, and as a result of using the authoring system to develop the two delivered exercises. Informal formative evaluations were conducted with the PACAF/DOC staff.

III. RESULTS

This project resulted in the production of an experimental prototype of a microcomputer-based training system called PACEXTRA. It runs on a Macintosh II computer and provides individualized exercise-based training to those preparing to perform duty as the Executive Officer in the PACAF Crisis Action System. The system demonstrates the concept of using low cost hypermedia software (SuperCard) to create a user-friendly exercise authoring tool, the implementation of which results in realistic event-driven exercises. These exercises put the trainee into a highly graphic on-screen environment, which is expected to provide high transfer of training to the real job environment. Exercises challenge the trainee with events about which he must make decisions regarding action to be taken. The system provides four levels of advice and the means of taking action in realistic job-like ways such as sending messages or contacting others, either directly or by phone. Feedback on what was expected and whether it was accomplished are provided for each event.

This project focused only on the design and development of the training system and included no evaluation or research on its effectiveness. Any such future research by AFHRL or others will be reported separately.

Advantages and Disadvantages of Approach

The advantages of employing a low cost, off-the-shelf, object-oriented, hypermedia-based software package like SuperCard is that it provides a great many of the features needed for interactive training systems, yet leaves the application of these features up to the imagination and ingenuity of the training system designer/developer. The ability to create, position, color, re-size, and add functionality to windows, cards, buttons, fields and objects without programming, and to then further enhance their functions with scripts, gives the designer/developer an ideal tool. However, the scripting language, due to its interpretive nature, runs very slowly, particularly on less than the top-of-the-line Macintosh hardware (fx model).

The true advantages and disadvantages of PACEXTRA as a training system will not be known until it is tested and employed in the field, which is beyond the scope of this project. However, experience in applying the PACEXTRA exercise authoring system has shown it to be very easy and efficient to use.

Potential Application

PACEXTRA itself, because it was designed specifically to train only the CAS Exec at PACAF, has no other potential direct application. However, the approach to event-driven exercise-based training which it exemplifies has application to nearly any event-related job. For example, it could be used to train store clerks on how to handle various customer situations. On the other end of the spectrum, it could be used to give space crews pseudo experience with mission events which necessitate their making decisions and taking actions. To convert PACEXTRA to train another job would primarily involve creating the proper graphic environment and the on-the-job tools. The underlying PACEXTRA system has generic application potential.

The real potential of the type of training system which PACEXTRA represents is to teach both procedural or rule-based decision making and knowledge-based decision making, particularly because it provides so much of the complex context of a decision environment. This is in contrast to procedural trainers which simply list "rules" or procedures with little sense of the "knowledge" that is gained by having experience in the decision context. This is the force behind expensive "virtual world" devices. The advantage of the PACEXTRA approach is low cost, availability, the focus on coordination of activities (i.e., teamwork), and speed of exercise authoring. There is little evidence to suggest the true need for the "glamor" of high tech reality. What is needed is the work-inspiring nature of an interactive environment. PACEXTRA appears to provide this, at low cost and with minimal effort on the part of scenario authors. Its potential seems to be significant.

Recommended Follow-on

As described elsewhere in the report, the event-driven exercise format of PACEXTRA has innumerable other potential applications, and the authoring system which it incorporates makes it relatively easy for trainers to create and modify training exercises. A natural follow-on, therefore, would be to modify the system (primarily the authoring system) so it focused upon another job and its environment, so that exercises could then be created to train that other job.

However, an even more useful follow-on would be to experiment with developing a higher level "authoring" process which would permit a training system developer to create their own exercise authoring system for their unique job. This higher level authoring process could then permit the exercise-based training exemplified in PACEXTRA to be applied to training any other job, without going through the time and expense of building the supporting tailored authoring system through programming. Rather, the trainers could develop their tailored authoring system themselves, through an interactive process similar to that of other interactive Macintosh applications. The result could add another dimension to the media and methods available in technical and operational training throughout the Air Force, and elsewhere. (Note: With the advent of Windows 3.0, and object oriented hypermedia applications such as Toolbook, this approach now appears practical on the IBM PC and compatible family of computers as well.)[1]

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[1]Rasmussen, J. Information Processing and Human-Machine Interaction. Vol. 12, North-Holland, NY, 1986.

Inexpensive Computer Based Training For Air Launched Weapons

Introduction

Training in the use of air launched weapons has received much positive recognition in the aftermath of the Persian Gulf war. Yet, the Naval aviation community is faced with a future of continually shrinking budgets. Programs thought to be untouchable, such as the A-12 and B-2 aircraft, have been restructured, reshaped, or simply reduced in size. The only forecast we can rely on is that the training community will be forced to do more with less. Knowing that a single Standoff Land Attack Missile (SLAM) costs $985,000, a single Harpoon missile $750,000 gives an appreciation that most of the tactical training for these and other costly weapons will not be accomplished by live firing. The costs of the weapons, launch and chase aircraft, telemetry equipment, and use of ranges make live firing opportunities more of an honor and a privilege than a means of training.

Large scale training devices and simulators have been used by the Navy to replace and to a lesser degree augment the training of Naval tactical aircrew. Flying hours are supplemented by the use of Operational Flight Trainers (OFT), and weapons training by Weapon System Trainers (WST) and Weapon Tactics Trainers (WTT). However, these devices do not represent a panacea for all training ills. First, they are very expensive to acquire, typically $50-$150 million, and once constructed require several people to operate and maintain. Second, most of these devices must operate continuously, around the clock, seven days per week, to meet the demands of the trainee population. Third, the capabilities of much of the Navy's arsenal of air-launched weapons are constantly being upgraded in response to the perceived threat. The lag time in upgrading large scale training devices can be up to two years, meaning that the student's simulator time will likely be spent with the last version of weapon system information, not the current version which has just entered the Fleet. Last, and most significantly, the training rendered by the large scale devices tends to be more procedural than engagement oriented.

The bottom line is this: the Navy has a need for training which allows tactical aircrew to practice weapon engagements repeatedly in tactically significant scenarios, using the most current version of the weapon and manner of integration into its host platform. Ex-Secretary of the Navy John Lehman was known to be a staunch supporter of expansion in the use of computer technology to aid the services in their mission. The author believes that the computer application to be presented here represents precisely that concept.

Early Developments in PC Based Training

In 1987, an PC based engagement trainer called HETA (Harpoon Engagement Training Aid) was fielded to assist Navy P-3C Orion aircraft Tactical Coordinators (TACCOs) in learning key employment factors for the popular Harpoon missile, an over the horizon, radar guided anti-ship weapon currently used by Naval surface, subsurface, and air platforms, as well as the Air Force. The Harpoon, once launched, operates autonomously under the control of its Midcourse Guidance Unit (MGU), initiating the radar search as a timed event based upon range to target at time of launch. So, in essence, the weapon once initialized with a manually entered targeting solution, operates on a "fire and forget" basis. This places the responsibility on the TACCO to send the weapon the best and most timely data available to attempt to maximize the probability of mission "success". The definition of "success" in this context is open for discussion, because the Harpoon cannot distinguish between a friendly platform, a hostile platform, or land; it simply attacks the first thing it sees, provided a steady radar return exists for a certain amount of time.

Before the existence of HETA, the Fleet Harpoon training consisted of the following elements:

* Review of tactical publications; lecture presentations

* Live Harpoon exercises in flight

* Training Sessions on Weapon System Trainers (Device #2F87T or 2F140T)

The deficiencies of this training are well documented, and can be synopsized as follows:

* Tactical publications, although useful as a technical backdrop for knowledge on weapon capabilities, are insufficient to train individuals in *tactical decision making*, which requires a synergistic assessment of many factors, including the probable launch environment (number of targets, targeting errors, weather, sea state, presence of land, presence of neutral and/or friendly platforms, etc.).

* Not only are live firings extremely limited in number, they tend to lack realism and are often "orchestrated" to ensure a successful outcome, with targets sitting dead in the water with their radar cross sections artificially augmented. (Even under these conditions, misses have occurred).

* WST sessions provide some sense of realism in portraying Harpoon scenarios. However, the only outcome information fed back to the student is "hit" or "miss", without an adequate reason for the particular outcome or a means of reconstructing the missile flyout to determine the reasons.

The initial HETA program was fielded with the hope that these training deficiencies would be greatly lessened. However, the developers soon learned that HETA needed much refinement and improvement. The comments received from the user community were numerous, generally constructive, and gave the developers the data required to truly attack the challenge of developing a useful computer based engagement training aid. Although not every reviewer agreed on each item, the following list is offered as critical deficiencies of the initial HETA trainer:

* The computer hardware (HP 9836C) is slow, has no hard drive, and requires too much swapping of floppy disks

* Too much interaction is required of the operator to get to the point where the weapon can be released. The targeting phase is slow.

* The only report on student performance is "hit" or "miss". (Sound familiar?) The student needs more information to improve his understanding of weapon employment factors.

* The target data base needs refinement; there were some inaccuracies and some data fields needed expansion. For example, with this weapon, it is not sufficient to simply know whether the target platform has guns aboard, the type of gun is critical.

* The keyboard of the HP 9836 does not resemble the P-3C TACCO tray (keyboard).

* The HP 9836 is not compatible with IBM or clone computers and there are only two of them available on site.

* Missile control panel representation in the HETA is crude and inaccurate.

and finally...

* The HETA system is not "fun" for the student to use.

Product Improvement Phase

Fortunately, sufficient positive feedback on the HETA was received to encourage the developers and the program sponsor that the basic approach, although admittedly needing refinement, was worthy of further exploration. With that goal in mind, the development team, which consisted of both contractors and Government personnel, met several times to discuss improvement strategies. The first and most obvious improvement required was replacement of the hardware. At the inception of the HETA program, the HP 9836C was chosen because it was the Navy's Standard Desktop Computer1. In addition to the problems noted in the previous section, the HP 9836 virtually required use of an arcane programming language (HP BASIC), known irreverently as "Rocky Mountain Basic" and an equally obscure graphics package. Also, after a brief and rather unsuccessful life, Hewlett Packard decided to discontinue the HP 9836C. Very few of these machines were actually bought, negating any chance for wide distribution of training software to users.

The Zenith 248 Desktop II computer was considered a promising replacement option for rehosting the HETA program. Unlike the HP 9836, this computer had been acquired in large quantities by the Navy, was almost always equipped with a hard disk, and was available for $1,100-$1,500, vice $14,000 for the 9836. These computers are of the AT class, run at 12MHz clock speed, and support EGA graphics. In order to run HETA on these computers, all that would have to be added to the standard hardware was a math coprocessor and a mouse, both available for about $400.

The second decision was to choose a programming language. The "C" language was chosen because it was well suited to simulation applications, supported the modularity needed, and posed no particular problem in blending text and graphic presentation. Most importantly, translation from BASIC to C was possible. (The original P-3C HETA software routines had been written in BASIC and were adapted to HP BASIC for hosting on the 9836.)

Finally, the developers agreed to incorporate, within the limits of practicality, many of the suggestions received from the users. A data base of these suggestions had been maintained, and would eventually prove invaluable toward increasing the training value of the fielded program. Because the P-3 WING training personnel frequently rotate and transition to other assignments, the development team also agreed to another round of design review meetings. It was important to ensure that the changes and upgrades planned mesh with Fleet weapon training curricula, and support current doctrine on the tactical uses of the weapon.

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1 The Navy actually has two standard desktop computer product lines. One, known as the "DTC" series, is designated for tactical usage, such as tactical decision aids, large data base intensive applications, and warfare analysis and engagement modeling. The other standard desktop computer is knwon as the "Desktop" series, used by the military for routine processing applications, and is very similar or identical to common PCs used in offices and homes. At the time of this writing, the current standards are the Sun Microsystems DTC II, and the UNISYS 386 Desktop III.

nctional Description

In less than one year, the developers were able to translate, improve and rehost the training program as required. The program is scheduled to be released to the Fleet in December 1991 and January 1992. The new HETA is structured as shown in Figure 1.

The TUTORIAL module contains a menu of topics designed to furnish both basic background for the novice trainee and somewhat more detailed knowledge of weapon capabilities as presently integrated with its host platform. Several interactive graphic lessons are available which provide dynamic display of the weapon's operating characteristics.

An example of the learning strategy employed in HETA can be demonstrated by describing the operation of three of the lessons contained in the TUTORIAL. The student has access to these functions through a mouse click or depression of a single softkey. The lessons are intended to be learned in ascending order of the TUTORIAL Main Menu (Figure 2). In Lesson #2, SEEKER SWEEP, a single cycle of the Harpoon radar seeker is dynamically drawn for the student in vivid color graphics. From this lesson, the student learns that if the search begins close to two targets, acquisition of the target immediately to the right is more likely. Detailed information on the performance of the seeker, such as minimum and maximum search ranges, sweep angles, and how range apertures are searched within a single sweep is portrayed. The PATTERN DEVELOPMENT lesson, [F3], illustrates the development of a Harpoon search pattern, and the variations resulting from the use of different variants of the missile, search pattern types, and range to target. Many combinations of these parameters are possible, since there are 4 different pattern selections, 3 missile variants, and range effects for two of the four patterns. The search options have much significance in the tactical use of the weapon. This is particularly true in the case of the P-3C, which as a long range air ASW platform, is a rather slow, unmaneuverable aircraft. Much emphasis is given to target prosecution at maximum standoff ranges and minimum detectability of the launch platform. The TARGET ACQUISITION lesson, [F4], demonstrates the acquisition logic of the weapon and guidance hold off delays. Graphically, this lesson is similar to PATTERN DEVELOPMENT, but is different because the student will be prompted to enter a number of land points and targets. Then, when he witnesses the missile flyout, with the search mechanism pictorially overlayed, the reasons for acquisition of a particular target, or land mass, will become exceptionally clear. Both the PATTERN DEVELOPMENT and TARGET ACQUISITION lessons give missile time of flight; the former to pattern completion and the latter to target (or land) contact.

Thus, the student is exposed to successively more complex topics in learning the operation of the weapon. This "layered" approach allows novices to start at the beginning and gradually build their understanding, and the more experienced to review only specific lessons of interest. At his option, a student may skip this module altogether and immediately proceed to the ENGAGEMENT TRAINING module.

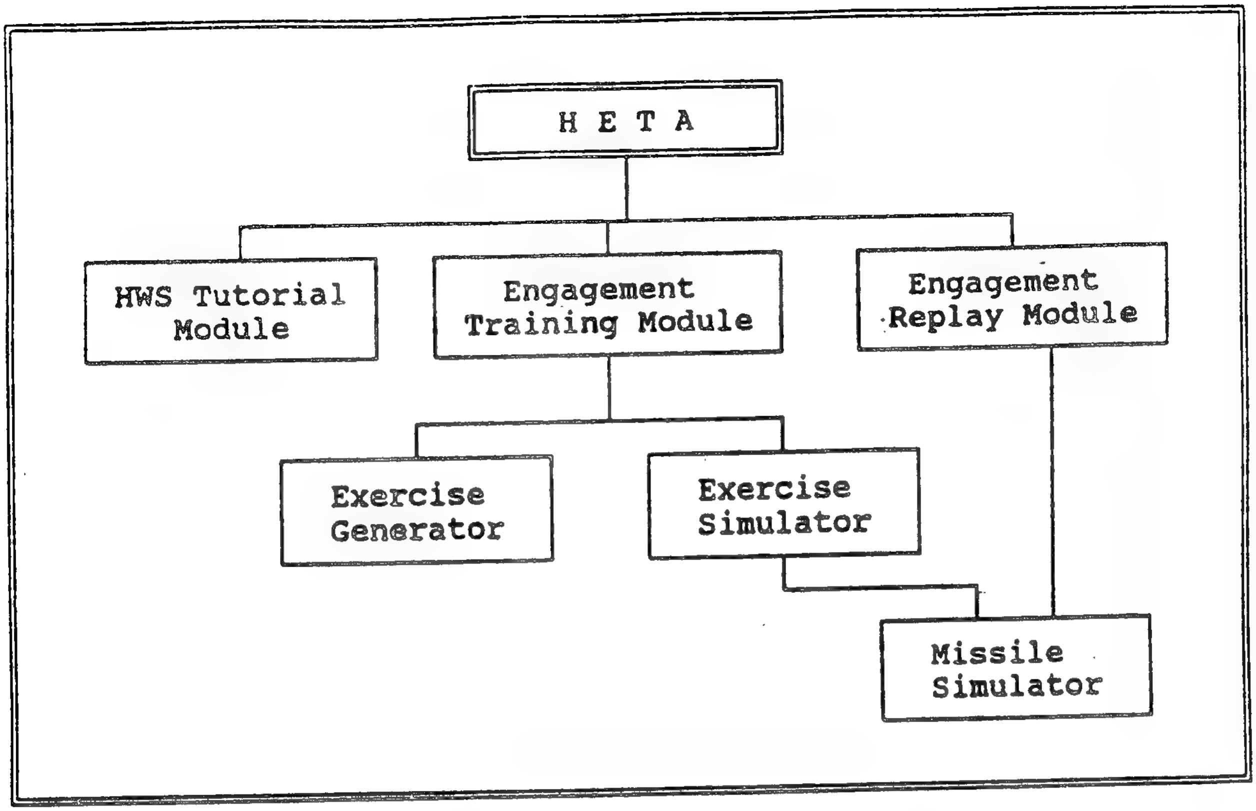

Figure 1. HETA Functional Hierarchy

Figure 2. Tutorial Main Menu

The ENGAGEMENT TRAINING module contains an EXERCISE GENERATOR, an EXERCISE SIMULATOR, and a MISSILE SIMULATOR. The HETA program is designed to allow creation, modification, and storage of Harpoon engagement scenarios. The depth of modelling and number of degrees of freedom which can be simulated on a PC comes as a surprise to most first time users of this training program. A table of capabilities of the EXERCISE GENERATOR is shown in Figure 3.

Function	Description of Capability	Range of Values	Default
Classification	Places classification banners in the tactical display area	CONFIDENTIAL SECRET	CONFIDENTIAL
Land	Allows selection of preprogrammed landmasses, modification of current or stored landmasses, and the simulation of coastline on TACCO's display.	No Land Land	No Land
Contacts	Contact management functions include: selection, reposition, contact maneuvers, contact removal, ESM emission schedule, contact library manager (database)	No Contacts (Bearing Only Launch mode) -10 contacts	No Contacts
Platforms	Place launch platforms; modify attributes {radar, ESM, max speed, max altitude, turn rate, accel/decel rates, climb/dive rates}; select 1 participating unit {list of 20}; reposition LP and/or PU; platform manevers; remove PU; platform and sensor library managers {define or modify attributes of platform and sensors in library}	Launch Platform only- Launch Platform and Participating Unit	Launch Platform
Scenario Pages	Insert real and perceived weather parameters {surface wind spd/dir, aloft wind spd/dir, ambient air temperature, rain rate, sea state}. Simulation control:{start time, range of visibility, grid lock rng/brg errors, aircraft equipment failures, and whether or not the operator gets radar class/ID, land points from radar operator, pause exercise capability}. Weapon loadout {allows loadout of Harpoon missiles on wing weapon stations}	Weather: Wind 0-100 kts Temp -16-120°F Sea State: 0-15 Douglas Rain: 0- mm/hr Weapon loadout: 0-6 missiles AGM-84A,C,or D	 0 kts 59°F 2 Douglas No Rain 6 AGM-84D missiles
Brief	Free format brief: a textual description of the mission objectives and guidance on how to execute SURPIC brief: actual mission brief used by P-3 community	0-13 lines text Blank SURPIC- Complete SURPIC	No text Blank SURPIC

File	File management system for EXERCISE GENERATOR. Load exercise, save current exercise, delete exercises, specify computer drive/directory to locate exercises and library files	N/A	N/A
Tools	Rescale screen Select a drop point {reference point for distance measurements} Clear exercise {clears and erases all information from tactical display and computer memory}	Screen Size: 5-512 NM 0-1 drop point	 256 NM No drop pt
Exercise Status	Status board for current exercise: {no. of platforms, no. of contacts, no. of land pts., modification status of weather parameters, weapon loadout, simulation control parameters, exercise brief, exercise valid/invalid (if invalid gives minimum information required to make current exercise valid)}	N/A	N/A

FIGURE 3.
EXERCISE GENERATOR CAPABILITIES

The EXERCISE SIMULATOR is used to run the scenario created or recalled from memory in the EXERCISE GENERATOR. In effect, this module places the student in the role of a P-3C TACCO, and he assumes responsibility for controlling the launch platform, operating the sensor suite to develop targeting data (and/or using targeting data from the participating unit), planning the Harpoon engagement, and executing the engagement by launching one or more missiles.

Enough replication of TACCO functions are provided for the student to perform procedures similarly to those used in the aircraft. Only functions required to support Harpoon engagements have been modelled. Some artificialities in mapping PC keyboard functions to TACCO functions were inevitable, but to date have not been tagged by Fleet representatives as a major hindrance to learning. An example of a required artifice is the method of flying the aircraft. Route control, as in the aircraft, is provided through the insertion of Fly-to-Points. (Steering computations are performed by the aircraft's tactical computer to provide automatic steering commands that will ensure capture of these points, which are actually two dimensional geographic "gates".) Speed and altitude, however, must be manually entered through operation of a PC softkey function.

The EXERCISE SIMULATOR display layout is shown in Figure 4. The identity of the switch legends in the "matrix functions" area vary according to main menu subgrouping. For example, switch [F1] is labeled TRACK at the main menu level. If [F1] is selected, all of the switch legends change as follows: [F1]=GENERATE TRACK, [F3]=PROBABILITY CONTOUR, [F4]=MOVING CIRCLE, [F5]=COMPUTE INTERSECTION, [F6]=PROJECT POSITION, [F7]=FIX DESIGNATE, [F8]=Probability of Acquisition, [F9]=MARK FIX, [F10]=Return (capitalized functions are in the same position and perform identically to TACCO functions in the aircraft). A complete listing of the simulated P-3C TACCO functions available is beyond the scope of this paper. Instead, typical task flow will be discussed below to give the reader a flavor for the SIMULATOR experience.

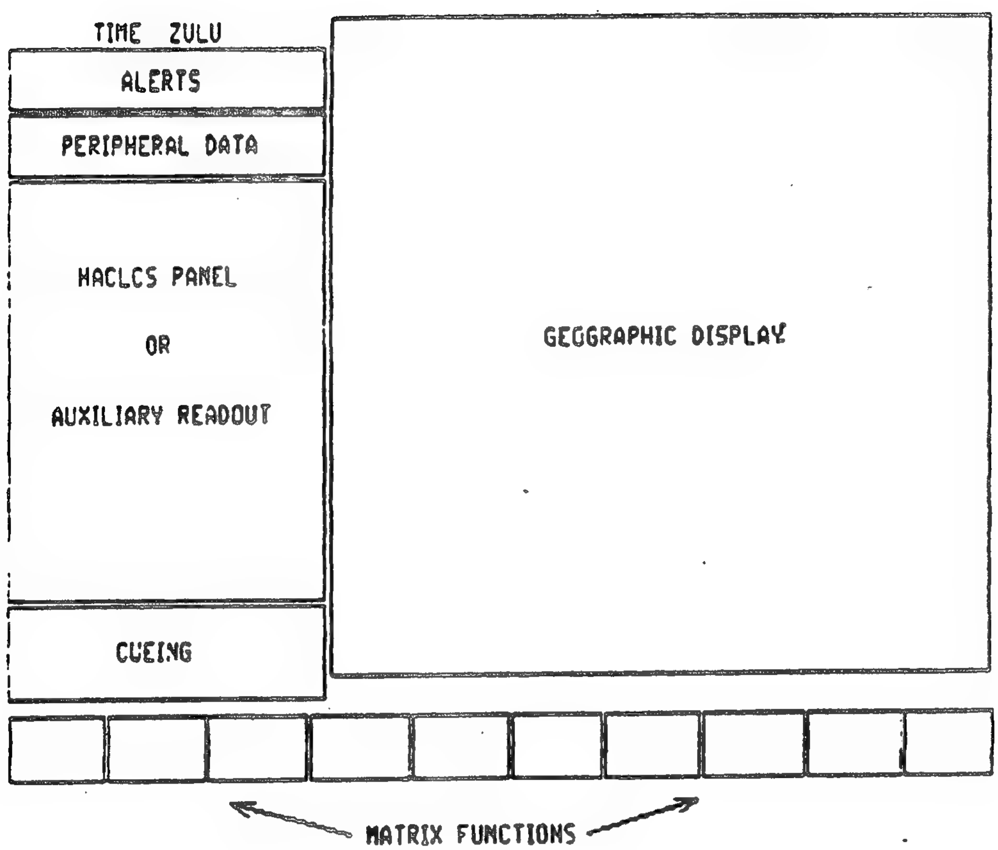

Figure 4. P-3C Exercise Simulator Display

pon entering the EXERCISE SIMULATOR, the TACCO is presented with a of 15 exercises from which to choose. The exercise brief is presented, f the system is equipped with a printer, perceived environmental data and nitial positions, courses and speeds of the lauunch platform and icipating unit are provided. Wind speed and direction, altitude and nd speed are provided on the display periphery. At this point, the ent will have to maneuver his aircraft to a position where he will be able se a sensor, usually radar, to detect potential hostile targets at a ance. Then the Sweep Radar function is used to locate contacts. The LIFY function is used to identify and classify contacts as targets. Fly to nts are entered to route the aircraft to a position from which the missile be used to prosecute the target. The HACLCS (Harpoon Aircraft Command nch Control System) Panel function is used to bring up a graphic, ctionally identical copy of the Missile Control Panel. The information on e tactical display will be used to develop a targeting solution, consisting ange, relative bearing, true air speed, and altitude is in turn ed" by use of the mouse onto the Missile Control Panel. Other lections, such as search pattern type, and missile station number are also ne via the mouse. Once a valid solution is entered, but before a missile is aunched, the student, using the Probability of Acquisition (Pacq) function, an ask the PC to determine the acquisition probabilities for each target, as ell as the probability of land and the probability of miss. No such function s available on the aircraft. This artifice allows a prelaunch analysis, and lso displays the areas which would have been searched. The overlay of search area onto target display is particularly valuable in assessing the quality of the targeting information as applied with the weapon. If the solution is acceptable, he may proceed with the launch. It is important to remember that in this phase of the problem, the student is dealing with imperfect information: sensor errors, missile guidance errors, navigation errors, and perceived environmental effects and conditions, which contain errors from reality. Therefore, in a tactical sense, the student's reality is no better worse than a TACCO's in an operational mission.

The MISSILE SIMULATION is the final component of HETA. The entire flight of the missile, from release to impact is dynamically displayed on the missile simulator display, which is partially represented by Figure 5. From the graphic display, the student is able to visualize the flight trajectory of the missile, seeker search, target acquisition, missile terminal guidance, and the effects of wind, temperature, and sea state. Once the missile simulation begins, a color coded trajectory line emananating from the launch platform is drawn as the Harpoon approaches its aimpoint. The codes correspond to the major flight segments (flyout, search, hold off, homing) found in the legend area. Also, simulation status messages are shown in the blank area just above the legend which indicate the current flight phase (release, presearch flyout, seeker turn on, searching, target acquired, holdoff, home on target, impact target, flight terminate). Because post flight analysis and reconstruction is the purpose of the MISSILE SIMULATOR, the student is provided with the ground truth positions, as well as the perceived positions of all contacts in the exercise. All missiles launched during the training exercise are reconstructed, one at a time. As each missile is successively simulated, the previous missiles' tracks are superimposed as "phantoms", in order to provide a sense of the totality of the engagement. Once the seeker is activated, each missile's radar search mechanism is dynamically shown on the display. Once all missiles have been flown out, the Complete Pattern and Pacq functions are

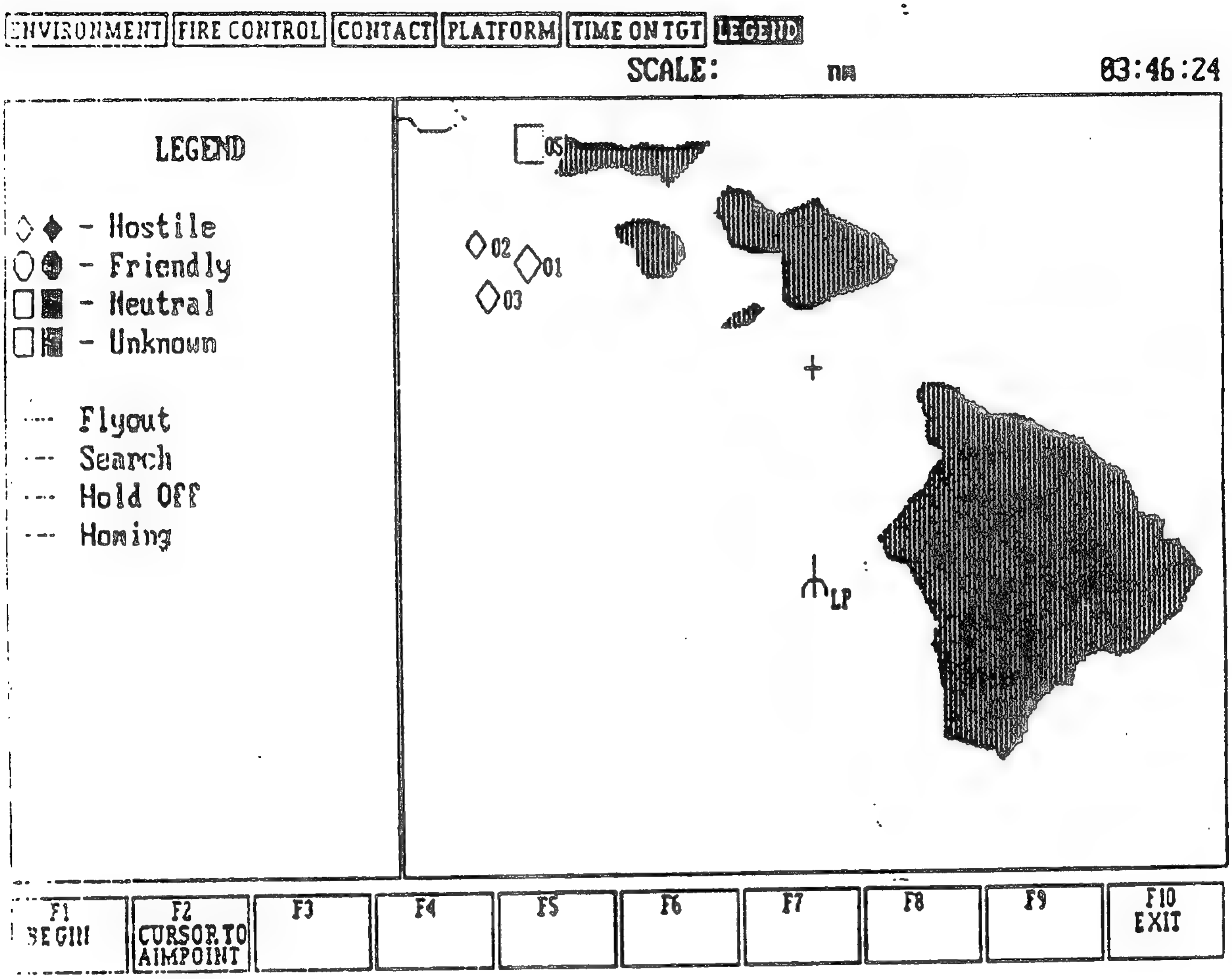

Figure Missile Simulator Display

available. Complete Pattern is used to display the entire area that would have been searched, if no target or land acquisition had occurred. This is of great value in determining the reasons why missile have failed to impact their intended targets, and therefore one of the most valuable functions in HETA. Pause and Continue features are included which allows the student to halt and resume pattern redraw at any time. The Pacq function gives a table of acquisition probabilities for all of the missiles in the exercise, and calculates each missile's acquisition probability against each target, land, and the probability that nothing is acquired. The Debrief function gives the time of occurence for launch, seeker turn on, acquisition, and engagement outcome for all missiles. It also gives a fairly comprehensive display or printout of all of the pertinent engagement variables, and reveals the true identity of all of the contacts in the exercise.

Cost Effectiveness

For a program capable of such detailed engagement training, the P-3C HETA program was remarkably cheap to produce. Software development costs ran about $250,000, program management and travel about $100,000, and life cycle maintenance costs to sustain the program for 4 additional years about $120,000. Dedicated training computers (UNISYS 386) are being fielded to support this program, as well as HETA's for other Harpoon platforms and engagement training aids for other airlaunched weapons, but the cost of these systems is irrelevant since HETA will run on the Desktop II or III. The HETA, once ready for Fleet use, can be distributed widely for training at extremely low cost. The development team usually conducts turnover training in order to expose the depth of the program's capabilities, particularly those found in the EXERCISE GENERATOR.

Other Engagement Training Aids

Aside from the P-3C HETA, a number of other engagement training aids have been developed and several others are under current development. For Harpoon Engagement Training, variants of the HETA program have been completed for the S-3B Viking aircraft and the A-6E Intruder aircraft. Over 40 HETA training systems are currently in use by the Fleet, including 4 systems in use on carriers. Additionally, a program called M on N (M shooters on N targets) has been developed to handle the pre-launch analysis and post-launch reconstruction of a mixture of carrier based Harpoon assets (e.g. S-3B, A-6E, F/A-18) utilized against one to ten targets. The M on N is different from the other HETAs, in that it lacks a TUTORIAL and an EXERCISE SIMULATOR, because cockpit procedures are not important here. The principal user for M on N HETA, the Naval Strike Warfare Center, will use this program to examine and refine tactical use of the weapon from the Carrier Air Wing staff perspective.

In addition to these variants of HETA, future versions of the program will be developed for surface ship launched Harpoon, submarine launched Harpoon, and a version that will provide on-board training by allowing transfer of launch data from the Harpoon Captive Air Training Missile onto a ground based HETA system.

Computer based engagement training programs have also been developed for the laser guided version of the Maverick missile (AGM-65E), and Bigeye Chemical Bomb (BLU-80/B). The latter weapon program was later cancelled in June 1990. Future PC based training programs are planned for the imaging infrared version of Maverick (AGM-65F), and the Mid-Range and Maritime Unmanned Air Vehicles.

Summary

Computer based engagement trainers such as the P-3C HETA fill an important gap in current training curricula by providing a tool that presents the student with the post launch consequences of the decisions made in the prelaunch, scenario evaluation phase of the mission. HETA reinforces the fact that to effectively engage the intended target requires a comprehensive knowledge of the weapon's capabilities, limitations, and the impact of the various error sources. The computer simulated prelaunch procedures, while not an exact replica of actual procedures, have been refined enough to avoid negatively impacting the training conducted in the classroom and on other devices. PATROL WING-11 at NAS Jacksonville, which consists of 6 P-3C squadrons, requires that TACCOs demonstrate their proficiency on HETA in order to qualify for Harpoon launch certification, and the HETA has also been used to explain the reason for hit/miss in reconstruction of Harpoon scenarios in the WST. To borrow the word of a member of the NATOPS Evaluation Team, "repetition is the key to training, and in particular for Harpoon training". In this respect, HETA has succeeded as a means of practicing those skills that will be essential in live firing operations.

Acknowledgements

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PC-based Electro-Optical Simulation Techniques With Application to the Maverick Engagement Training Aid (META)

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SLIDE 1

I. Introduction

One often hears that models will be tested and validated based on Fleet data. By tested and validated, the designer is not necessarily implying that the models are to be"operationally and factually based." What the designer actually means is that more data is better than less data. However, because no model will ever be constructed with complete realism and factual certainty, the real question to be addressed by the model developer is how much "operational and factual" basis is he willing to buy.

In 1986, KETRON was contracted to build PC-based training aids for the laser and infrared variants of the Maverick missile. At the start of the effort, PC-based models were not available to simulate electro-optic energy acquisition within the training community. To meet our contractual obligations to NAVAIR, we "bootstrapped." "Bootstrapping" applied to EO modelling means that we came up with a strategy which incorporated simplicity and economy of effort to keep the modelling cost down.

SLIDE 2

The purpose of this paper is to summarize our "bootstrapping" approach to EO modelling used in the development of PC-based training aids for the laser and Infrared Maverick missiles. This paper is motivated in part by the complexity in simulating EO engagements on a microcomputer. In addition, the topic is meant to underscore the importance of validation in the lifecycle support of PC-based training devices. In this regard we will show how we validated our method using well established practices of statistics and operational analysis of small samples of Fleet data. Finally in support of PC-based initiatives taken by PMA 205 over the last 5 years, our goal is to motivate the Fleet training community to use PC training devices as an important tool in achieving weapon training.

SLIDE 3 Computer Based Training

II. Background

The principal NAVAIR goal for PC-based training devices is to provide an affordable means of training aircrews, instructors, and civilian training specialists in all facets of weapon handling and delivery procedures. By design, each training device includes a tutorial on weapon hardware, exercise generators for mission planning, and a simulation module designed to test user understanding of missile performance during real-time computer simulation. These devices are currently being developed for HARPOON and MAVERICK missiles and implemented on standard GFE microcomputers equipped with EGA/VGA graphics, 80386 processor, and mouse interface.

Of the many issues facing the life-cycle support manager of EO training devices, validating simulation courseware for training instructors and aircrews is the most problematic. By life cycle support, we mean the overall process of establishing and maintaining the integrity of a training device throughout its useful life through provisions of operational, logistical as well as technical support. In the case of EO training aids, development problems are accentuated because the requirements for simulation accuracy vary across different user communities and provisions for model validation and verification are not well understood by life cycle support managers.

As shown below, we have attempted to develop EO courseware for Maverick with a clear focus on model validation issues.

III. Scope

Before discussing our approach, a brief word on the scope and importance of EO modeling techniques to the DOD is an appropriate prologue.

Growing DOD Emphasis on EO Technology

As shown on the slide a considerable number of NAVY weapons depend on EO sensors for detection, acquisition and tracking.

(Slide 4) **Laser Designators and Laser-guided Weapons**

-MAVERICK Missile (TV\Infrared\Laser)
-TOW
-WALLEYE
-HELLFIRE
-SLAM
-Shipboard Infrared Search and Track (IRST) system
-Laser Designators (MULE\LDT)
-SIDEARM

In view of the DOD investment in EO weapons by the DOD, we assumed at the start of the effort that we could find an EO model that had been validated by the DOD and adapt it for Maverick. At a minimum, we needed access to a Maverick database to develop empirical models for predicting performance.

We found out that in the late 1970's, US DOD directed the joint services to provide a capability by 1984 to measure, model and predict accurately the atmospheric transmission effects on DOD sensors and communications system. The roles were assigned as follows:

DOD Role in EO Modelling

SLIDE 5

a. Army:

Measure and model atmospheric propagation conditions for battlefield conditions. Develop models describing natural and artificial dust, smoke and chemicals and their propagation characteristics. Develop battlefield diffusion models to relate propagation conditions to meteorology.

SLIDE 6

b. Air Force:

Maintain approved DOD standard atmospheric optical models. Publish and brief model updates annually. Conduct a tri-service annual review conference to provide for tri-service discussion of model deficiencies and model propagation effects of the free atmosphere, including the ionized atmosphere above 50 km.

SLIDE 7

c. Navy:

Measure and model atmospheric propagation conditions as affected by the marine environment.

SLIDE 8

d. All Services:

- Develop relationships between meteorological measurements and aerosol models.
- Conduct adequate meteorological and propagation measurements in conjunction with systems tests.
- Develop and validate systems performance models based on weather climatologies.

The most widely acclaimed EO model, LOWTRAN, is owned by the Air Force and runs on a main frame computer located at Massachusetts site of the Air Force Geophysics Laboratory, now known as Phillips Laboratory/Geophysics Directorate (PL/GP). Accessing LOWTRAN from a main frame computer was impractical for META considering the large amount of access required. Moreover, documentation on the model inputs suggested that attempting to write code for the complex models used in LOWTRAN was beyond the scope of what was required for a training device, especially in the prototyping stage of development.

SLIDE 9

We discovered however that a considerable effort was underway to convert LOWTRAN into a Zenith 248 format for the purpose of supporting PC-based EO Tactical Decision Aids.

As shown in the list of EO models, PC-based models were not to become available until the late 1980's or early 1990's. While waiting on this conversion, we opted to take a heuristic "bootstrapping" approach in developing EO acquisition models for META.

SUMMARY OF EO MODELS

DOD EO Models	HOST COMPUTER	AGENT	IOC
•LOWTRAN	Main Frame	Air Force	Early 1980's
•MODTRAN	" " "	Air Force	Early 1980's
•SENTRAN	" " "	Germany	Early 1980's
•PCTRAN	Microcomputer	Air Force	Late 1980's
•MKIII EOTDA	Microcomputer	Air Force	Early 1990's

IV. Discussion

We will now summarize our "bootstrapping" process across four development periods or phases:

SLIDE 10

- Phase I (1987-1989) Empirical Methods based on Laser Maverick OT Data
- Phase II(1989-1990) Theoretical Methods based on Hughes Model
- Phase III(1990-1991) PC-based Software Investigation
- Phase IV (1991-1992) MK III EOTDA and Real World Data

A. Phase I (1987-1989): Prototype AV-8B Laser META

Collecting operational data is the essential first step in the "Bootstrapping" procedure in that the data, however small, inherently will account for the interrelationships and uncertainties of human and mechanical factors. A summary of the data made available to us at the start of the effort is shown on the next slides.

(SLIDE 11)

Data on EO designation range versus operator pointing error and designator to target angles were obtained through the NAVY Maverick Program Office (PMA 242).

(SLIDE 12,13)

These data points were supplemented by Commander, Operational Testing and Evaluation Forces (OPTEVFOR) data on Laser Maverick launches for the A-4E and A-6E during initial operation test and evaluation (IOT&E). A total of 51 Laser Maverick launches from A-4M, A-6E, and AV-8B aircraft were used to correlate ground designation and Maverick seeker acquisition range with visibility, target type, aircraft altitude, and target range.

SLIDE 14

The second step of the "bootstrapping" approach is the development of heuristic algorithms to be used in computer simulation. In this regard, regression equations were derived for each set of parameters identified in the operational data to test the dependencies and relationships. R-squared estimators, t-values, and regression coefficients were checked to verify that the equations and their variables were statistically significant. The residuals of the regressions were examined for patterns which could possibly improve the equations. The Durbin-Watson Test for each regression was performed and checked for problems with autocorrelation. Finally, a randomized block analysis of variance (ANOVA) was performed to investigate the variability of each treatment's mean and the variability of each block.

Using these techniques, a simple relationship was developed to associate Maverick seeker acquisition range with designation range.

(SLIDE 15, 16) Show plots of the data and the predictive equation

<u>Lessons Learned in Phase I</u>

The results of Phase I modelling lead to the following conclusions:

(SLIDE 17)

- "Bootstrapping" methods applied to operational data are very cost effective in training system simulation
- "Bootstrapping" results are sufficient estimates of upper and lower bounds on EO sensor performance
- "Bootstrapping" algorithms are not suited for EO training courseware i.e. derived equations represent the data only, not the physical phenomena involved.

B. Phase II (1989-1990): AV-8B META Fleet Introduction

After two years of prototype development, Maverick simulation requirements shifted toward training instructors and Navy Civilian Training Specialists (NCTS). As a result, a more formal approach to EO simulation and courseware was required in META. By courseware, we are referring to a combination of text, graphics and interactive exercises implemented on a microcomputer.

To meet the requirement for formal EO courseware in META, we incorporated a laser acquisition model used by Hughes and recommended by the Maverick Program Office (PMA-242).

Simulation Model

(SLIDES 18-32 from META)

As observed from the Hughes model, only four inputs are required to get an estimate of acquisition range.

Parameters: Attenuation, EO Energy, Target Reflectance, Seeker Sensitivity

Model: Acquisition Range based on Minimum Energy Received at the target

Paradigm: Compute Acquisition Range

Exercise: Maverick seeker acquires the target when the receiver sensitivity threshold has been exceeded. A flashing "X" on the synthetic display indicates Maverick has acquired sufficient, properly-coded energy to exceed its' receiver sensitivity threshold.

Lessons Learned from Applying Hughes Model to Phase II Results:

As far as comparison with Phase I results, we found that the Hughes model outputs were generally higher than the empirical results obtained in Phase I.

- Complements "Bootstrapping" method used in Phase I
- Sensitive to Inputs for meteorological visibility
- Limited in accounting for human involvement and transmission phenomena

(For example, see the variation in meteorological range in Table 1.)

Table 1. Variations in Meteorological Range (Bad Weather)

Weather	Meteorological Range (meters)
Dense fog	<50
Thick fog	50 - 200
Moderate fog	200 - 500
Light fog	500 - 1000
Thin fog	1 - 2 km

Table 2. Variations in Meteorological Range (Good Weather)

Weather	Meteorological Range (kilo-meters)
	Metric
Clear	10 - 20
Very clear	20 - 50
Exceptionally Clear	>50

C. Phase III (1990-1991): Infrared Modeling for F/A-18 META Applications

In early 1989 as we began to transition from laser to infrared modeling, the Air Force began to make LOWTRAN output available to the DOD community in the form of PC-based programs called the PCTRAN series. With the aid of on-line LOWTRAN output, we would be able to expand our modelling parameters and extend META potential in the area of mission planning and rehearsal.

SLIDE 35 (Refer to Picture)

PHASE III EO MODEL DESIGN PARAMETERS

- Designation Energy
- Transmission Loss at Target
- Energy Reflected From Target
- Energy Concentration at Seeker

Input Assumptions

SLIDE 36

1) Laser Maverick System (1.06 micron wavelength)

2) Neodymium YAG Laser Designator with 100mj designator power, 20ns laser pulse (5 megawatts (MW).

3) Airborne self-designation aircraft (A-6E on F/A-18)

DESIGNATION ENERGY

SLIDE 37

Inputs

DP = Designator Power (Mega Watts)
PL = Laser Pulse Length
[Note: this is not PRF] (Nanoseconds)
BW = Band Width of Beam (Microns)

Note: For purpose of META modeling of Maverick: DP = 5 MW (5.0 X E06 watts); PL = 20ns (20 x E-09 seconds); BW = .002 microns

Output

ES = Energy at Start of Designation (millijoules)

SLIDE 38

Algorithm 1.0

$$ES = DP * PL$$

TRANSMISSION TO TARGET

SLIDE 39

Inputs

SL = Slant Range (feet)

VI = Visibility (or weather condition; in this case, it (feet) would be converted to a visibility number)

AL = Altitude of Airplane (feet)

Output

TR = Transmittance Distance (feet)

SLIDE 40

Algorithm 2.0
TRANSMITTANCE EQUATIONS

Visibility (km)	Equation
23	TR= -0.042SL + 0.90
15	TR= -0.048SL + 0.81
6	TR= -0.038SL + 0.44
3	TR= -0.011SL + 0.115

ENERGY REFLECTED BACK TO DESIGNATOR

SLIDE 41

Inputs

ET = Energy Transmitted to Target
ES = Designation Energy at Start
TR = Transmittance
SO = Energy Spillover
EA = Energy Absorbed

Based on the above inputs, we derive the following EO model for Phase III:

SLIDE 42

Algorithm 3.0

ER = ES*TR - (SO*ET) - (EA*(ET-(SO*ET)))

ER is the energy in millijoules which is being reflected back towards the laser designator.

AREA OF ENERGY CONCENTRATION AT SEEKER

The energy concentration at the seeker is modeled as the energy per square meter of area over which the laser beam is spread. During designation, the beam is coherent and thus

the energy is very concentrated upon its arrival at the target. But when the laser makes contact with the target, it is reflected back in many directions, spreading the energy out.

(SLIDE 43): Discuss the Energy Concentration Model:

To calculate the energy concentration at the seeker, we need to model the area which the energy is spread over.

AREA OF ENERGY CONCENTRATION AT SEEKER

Inputs

SS = Spot Size (inches)
SL = Slant Range (km)

Output

AC = Area of Concentration at Seeker

SLIDE 44 (Discuss Picture)

where AC is calculated as follows:

Algorithm 4.0

$$r=(\frac{SS*2.54}{100(2)})$$

$$R=(SL*1000)+r$$

$$AC=\pi R^2 \text{ [Square meters]}$$

ENERGY CONCENTRATION AT SEEKER

SLIDE 45

Inputs

ER = Energy Reflected Back (millijoules)
AC = Area of Concentration (square meters)
TR = Transmittance Calculation

Output

EC = Energy Concentration at Seeker

SLIDE 46

Algorithm 5.0
EC = (ER/AC) * TR Millijoules Per Square Meter (mj/m^2)

DETERMINE IF ACQUISITION OCCURS AS PREDICTED IN PHASE I

SLIDE 47

Inputs

SE = Seeker Sensitivity (millijoules per square meter)
EC = Energy Concentration at Seeker

Note: For Laser Maverick, assume a sensitivity between $2.1X\,10^{-9} mj/m^2$ and $10.2X\,10^{-9} mj/m^2$

Output

EC > < SE

Algorithm 6.0
If EC > SE then acquisition is possible. Otherwise, declare acquisition is not possible.

STATISTICAL COMPARISON OF LOWTRAN WITH PHASE DATA

Phase I operational data showed a somewhat surprising closeness with LOWTRAN data output as shown by the following regression equation:

SLIDE 48

LOWTRAN Acquisition Range (kft) = 1.1811 + (.8369) X Phase I Range (kft)

Statistical analysis of the data determined an R-squared value of 0.8763 and a standard deviation of 8.4188 (kft). In statistical parlance, we conclude on the basis of these low values that LOWTRAN and Phase I operational results are not significantly different. Furthermore, these results imply that LOWTRAN results represent upper bounds on EO performance.

<u>Summary of Phase III Lessons Learned</u>

SLIDE 49

- Greater confidence was established in META results obtained in Phase I
- Accuracy of Phase II "Bootstrapping" approach depends on the number of equations used to predict transmittance
- LOWTRAN parameters would be preferred for Mission Planning and Tactical Decision-making

D. PHASE IV (1991-1992). (Development of A-6E Laser/Infrared META)

Currently, we are in Phase IV of development and are focusing our attention on requirements for Maverick training aids within the Navy's A-6E community. Strategies for implementing EO simulation on micro-computers for NCTS personnel, training officers and A-6E aircrews are influenced by a combination of aircrew desires that EO training devices contain courseware for tactical decision-making.

To meet this requirement economically, we plan to incorporate target lists and environmental databases developed by the armed services and implemented in the MKIII EOTDA developed by the Air Force. In addition, we will examine operational data to establish bounds on laser and infrared designation and acquisition performance. We plan to use data obtained in the Persian Gulf War to supplement IR data we have in-house to establish operational bounds. If upon comparing these results to MKIII EOTDA data we find a large disparity in the results, our experience has taught us to rely heavy on the operational data. This is especially true if the ultimate training device is to be validated for use in mission planning and tactical decision-making. The following database comparisons illustrate the potential improvement in META simulation planned for Phase IV.

PHASE IV Database Forecasts

SLIDE 50

	META Current	MKIII EOTDA Available	META Projected (PHASE IV)
Number of IR Targets	2	24	10
Number of Laser Targets	2	43	20
Number of IR Backgrounds	0	38	20
Number of Laser Backgrounds	2	169	20

With the MKIII Electro-Optical Tactical Decision Aid (MKIII EOTDA) now available, we have access to a number of submodels developed by the DOD to simulate laser and infrared acquisition. It should be noted that MKIII EOTDA cannot run under META as a subroutine. Although we do have source code for LOWTRAN, the cost required to adapt LOWTRAN to META is beyond the scope of our contract. These EO submodels are identified below:

SLIDE 51

INPUT REQUIRED GENERALLY FOR LASER SUBMODELS

Submodel	Number of Input Parameters
Target Background	2
Transmissivity	12
Sensor Performance	9
Designator Range	3

SLIDE 52

INPUT REQUIRED FOR INFRARED SUBMODELS

Submodel	Number of Input Parameters
Insolation	9
Sky Radiation	4
Target Contrast Model	16
Transmittance	12
Sensor Performance	11

As observed from the large number of parameters required by the laser and infrared submodels, a large amount of time would be required to input data into MKIII EOTDA format. In keeping with our "Bootstrapping" approach, we have identified a smaller subset of inputs to build simulation models around A-6E training requirements.

SLIDES 53, 54, 55, 56

V. Conclusions

SLIDE 57

To summarize the important results, findings and lessons learned over the past four years of EO "Bootstrap" modelling, we offer the following.

- Over twenty years of progress made by the DOD in EO research and modelling have been incorporated into Maverick PC-based training devices as a result of the META program.

- "Bootstrapping" methods have worked just fine and have kept overall training system costs down.

To training system developers, we offer the following tenets of good "Bootstrapping" procedures:

SLIDE 58

-● Accept little data over no data

-● Do not over invest in rigor and sophistication

-● Temper patience with progress

-● KISS (Keep it simple) Always

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PC-based Electro-Optical

Simulation Techniques

With Applications to the

Maverick Engagement Training Aid (META)

Jerry West, D.Sc.
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KETRON Division of the
BIONETICS Corporation

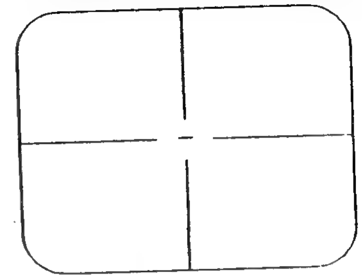
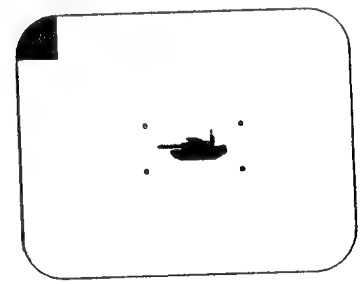
Slide 1

PURPOSE

- Discuss the complexity in simulating EO engagements on a microcomputer
- Summarize the "bootstrapping" approach to EO modelling
- Underscore the importance of model validation
- Motivate the use of PC-based training devices

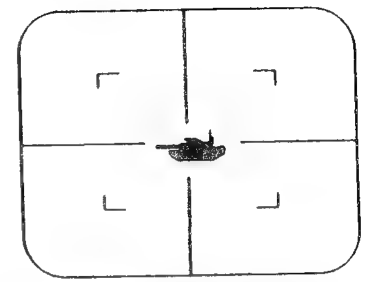
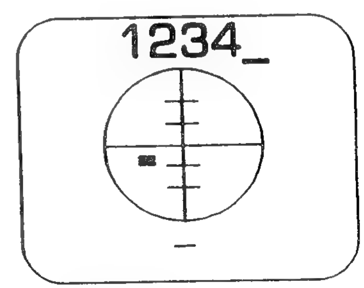
Slide 2

EO MAVERICK MISSILE FAMILY

GUIDANCE	DESIGNATION	GUIDANCE TECHNOLOGY	DISPLAY PRESENTATION
TV	AGM-65A	• TV FOV • CENTROID/ CONTRAST TRACKER	 REAL-TIME TV
	AGM-65B	• TV FOV IMPROVED CENTROID/ CONTRAST TRACKER	 REAL-TIME TV

Slide 3

EO MAVERICK MISSILE FAMILY

GUIDANCE	DESIGNATION	GUIDANCE TECHNOLOGY	DISPLAY PRESENTATION
IR	AGM-65D AGM-65F AGM-65G	• IMAGING IR • DUAL FOV • DIGITAL TRACKER	 IMAGING-TV DISPLAY
LASER	AGM-65E	• PASSIVE LASER • DIGITAL TRACKING	 SYNTHETIC DISPLAY

Slide 3 (Continued)

LASER DESIGNATORS AND LASER-GUIDED WEAPONS

-MAVERICK Missile (TV\Infrared\Laser)

-TOW

-WALLEYE

-HELLFIRE

-SLAM

-SIDEARM

-Shipboard Infrared Search and Track (IRST) system

-Laser Designators (MULE\LDT)

Slide 4

ARMY

- Measure and model atmospheric propagation for battlefield conditions
- Develop models describing natural and artificial dust, smoke and chemicals
- Develop battlefield diffusion models

Slide 5

AIR FORCE

- Maintain approved DOD standard atmospheric optical models
- Publish and brief model updates annually
- Conduct a tri-service annual review

Slide 6

NAVY

Measure and model atmospheric propagation conditions as affected by the marine environment

Slide 7

ALL SERVICES

- Develop relationships between meteorological measurements and aerosol models
- Conduct adequate meteorological and propagation measurements in conjunction with systems tests
- Develop and validate systems performance models based on weather climatologies

Slide 8

SUMMARY OF EO MODELS

DOD EO MODELS	HOST COMPUTER	AGENT	IOC
• LOWTRAN	Main Frame	Air Force	Early 1980's
• MODTRAN	Main Frame	Air Force	Early 1980's
• SENTRAN	Main Frame	Germany	Early 1980's
• PCTRAN	Microcomputer	Air Force	Late 1980's
• MKIII EOTDA	Microcomputer	Air Force	Early 1990's

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EO MODELLING FOR META

- Phase I (1987-1989) Heuristic Methods
- Phase II (1989-1990) Theoretical Methods
- Phase III (1990-1991) PC-based Software
- Phase IV (1991-1992) MKIII EOTDA and Real World Data

Slide 10

Laser Designation Ranges (1000 x feet)
MULE vs. 15' x 15' Tank Data

Pointing Error (microradians)	0°	Target Angle 30°	(Degrees) 45°	60°
.00	36.98	32.50	26.34	18.45
500.00	[illegible] 16	12.11	10.53	7.37
1000.00	7.58	7.11	6.05	4.21

Slide 11

Acquisition Range vs. Designation Range and Visibility Seeker at 150 feet

Designation Range (X 1000 ft)	Visibility 5KM	10KM	23KM	40KM
0	19	28	44	54
5	18	26	42	52
10	15	23	38	20
30	5	15	30	42

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Acquisition Range vs. Designation Range and Visibility Seeker at 15,000 feet

Designation Range (X 1000 ft)	5KM	Visibility 10KM	23KM	40KM
0	40	55	64	72
5	29	45	62	70
10	20	37	57	65
30	10	12	42	55

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ANALYTICAL TOOLS

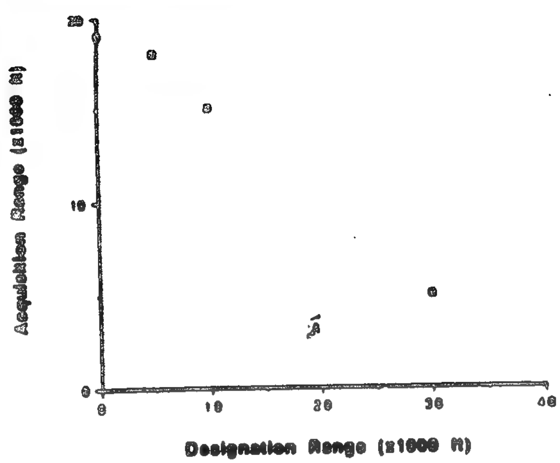
- Regression equations
- R-squared estimators
- T-values
- Durbin-Watson Test
- Randomized block analysis of variance (ANOVA)

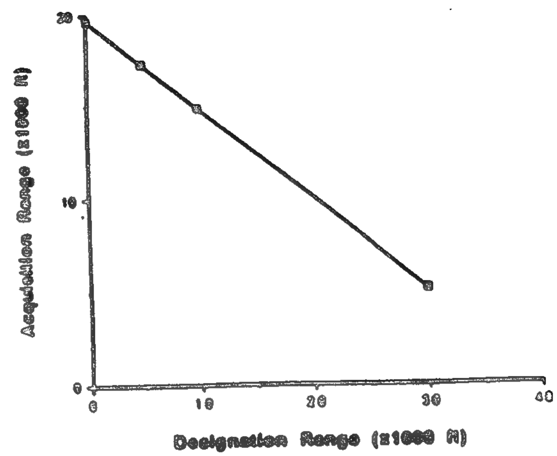
Slide 14

DATA PLOTS

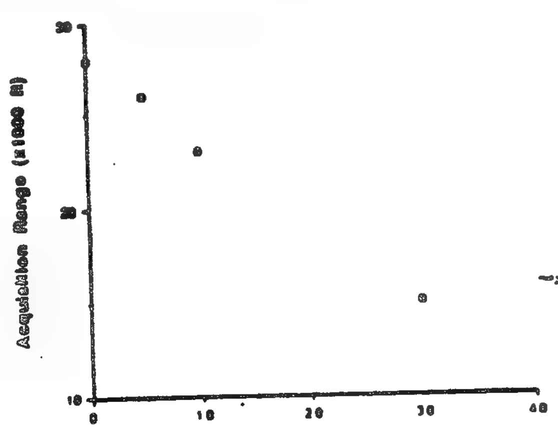
REGRESSION CURVES

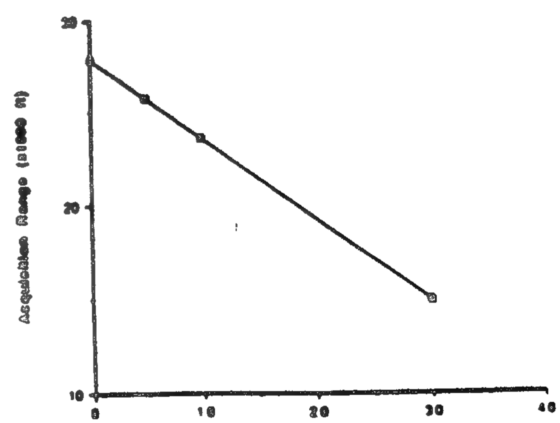
5 Km VISIBILITY





10 Km VISIBILITY

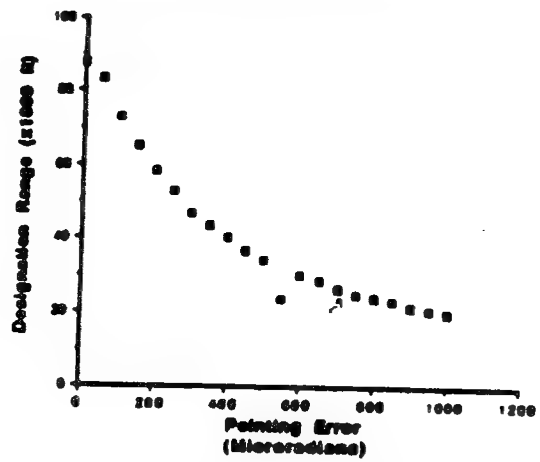


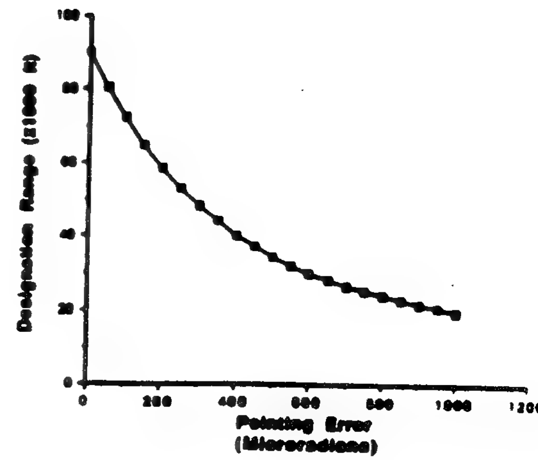


DATA PLOTS

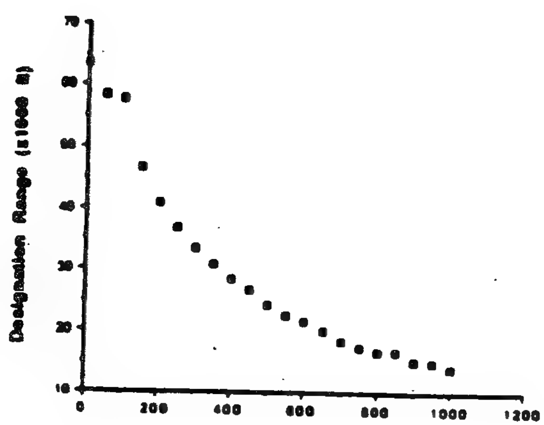
REGRESSION CURVES

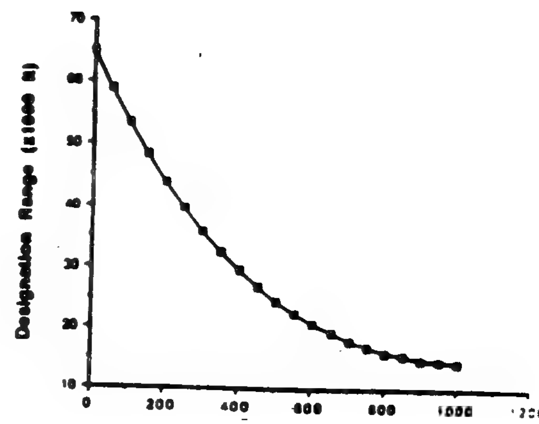
TARGET ANGLE 45 DEGREES





TARGET ANGLE 60 DEGREES





LESSONS LEARNED IN PHASE I

- "Bootstrapping" methods are sufficient in prototyping training devices
- Operational test data are best suited for establishing upper and lower bounds
- "Bootstrapping" equations have little to do with reality

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METEOROLOGICAL RANGE VARIATION
(Bad Weather)

Weather	Meteorological Range (meters)
Dense fog	< 50 m
Thick fog	50 - 200
Moderate fog	200 - 500
Light fog	500 - 1000
Thin fog	1 - 2 km

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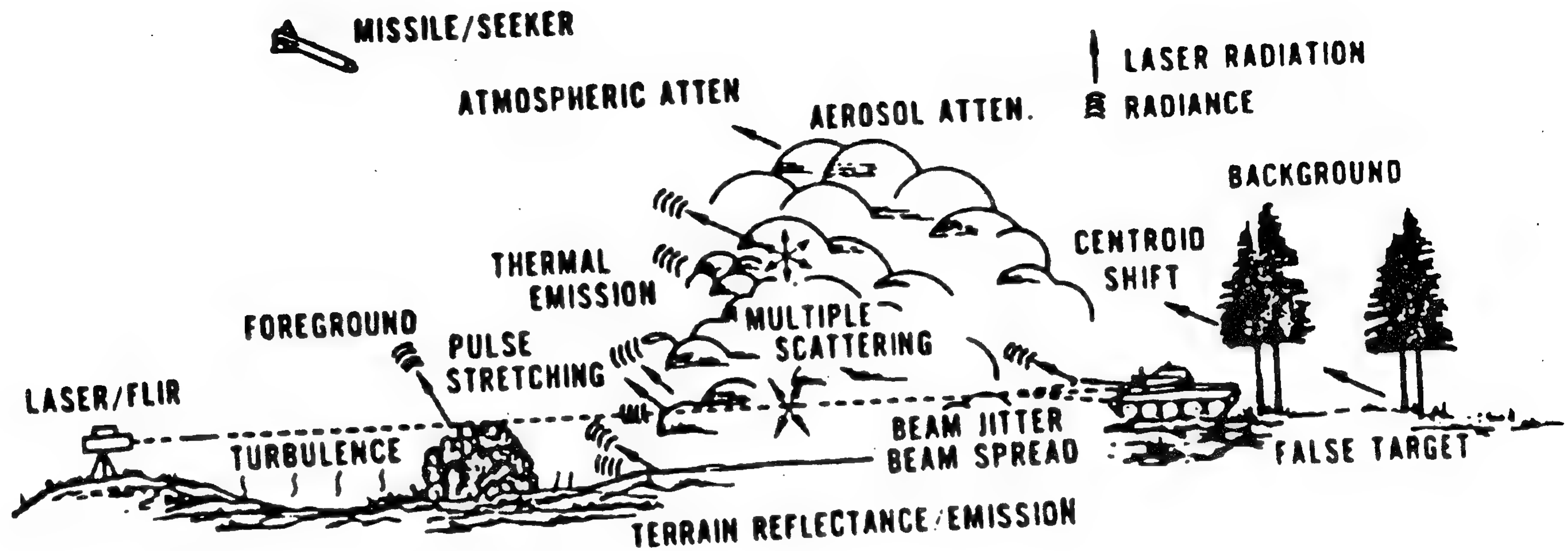
METEOROLOGICAL RANGE VARIATION
(Good Weather)

Weather (kilometers)	Meteorological Range
Clear	10 - 20
Very clear	20 - 50
Exceptionally clear	>50

Slide 34 (Continued)

ENVIRONMENTAL FACTORS AND EFFECTS



LOWTRAN INPUT ASSUMPTIONS

1) Laser Maverick System

2) Neodymium YAG Laser Designator

3) Self-designation aircraft (A-6E or F/A-18)

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DESIGNATION ENERGY

Inputs

DP = Designator power

PL = Laser pulse length

BW = Band width of beam

Output

ES = energy at start of designation

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DESIGNATION EQUATION

$$\boxed{ES = DP * PL}$$

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TRANSMISSION TO TARGET

Inputs

SL = Slant Range

VI = Visibility

AL = Altitude of Airplaine

Output

TR = Transmittance Distance

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TRANSMITTANCE EQUATIONS

Altitude Band	Visibility (km)	Equation
0 - .1	23	$-0.042SL + 0.90$
0 - .1	15	$-0.048SL + 0.81$
.1 - 1	23	$-0.040SL + 0.92$
.1 - 1	15	$-0.048SL + 0.82$

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ENERGY REFLECTED BACK TO DESIGNATOR

Inputs

ET = Energy Transmitted to Target

ES = Designation Energy at Start

TR = Transmittance

SO = Energy Spillover

EA = Energy Absorbed

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RECEIVED ENERGY EQUATION

$$ER = ES*TR - (SO*ET) - (EA*(ET-(SO*ET)))$$

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AREA OF ENERGY CONCENTRATION

Inputs

SS = Spot Size

SL = Slant Range

Output

AC = Area of Concentration at Seeker

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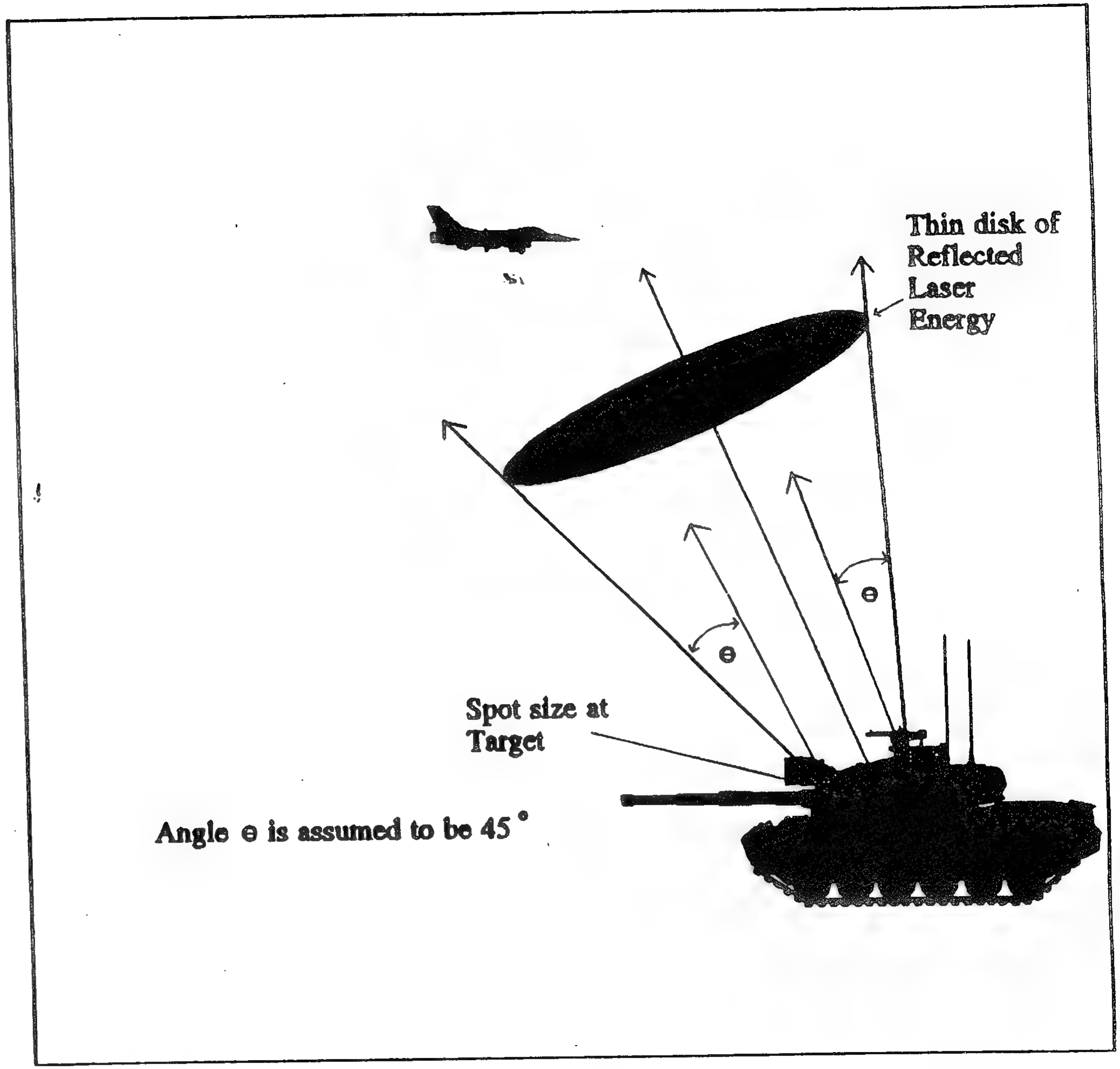
Thin disk of Reflected Laser Energy
θ
θ
Spot size at Target
Angle θ is assumed to be 45 °

ENERGY CONCENTRATION AT SEEKER

<u>Inputs</u>

ER = Energy Reflected Back

AC = Area of Concentration

TR = Transmittance Calculation

<u>Output</u>

EC = Energy Concentration at Seeker

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SEEKER ENERGY

$$\boxed{EC = (ER/AC) * TR}$$

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DETERMINE IF ACQUISITION OCCURS

Inputs

SE = Seeker Sensitivity

EC = Energy Concentration at Seeker

Output

EC > < SE

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STATISTICAL COMPARISON OF LOWTRAN AND PHASE I PREDICTIONS

LOWTRAN Range = 1.1811 + (.8369) * Phase I Range

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SUMMARY OF PHASE III LESSONS LEARNED

- Greater confidence achieved in META results obtained in Phase I
- Accuracy of "Bootstrapping" approach depends on the number of equations used to predict transmittance
- LOWTRAN output required to improve flexibility of META EO modeling

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PHASE IV DATABASE FORECASTS

	META	MKIII EOTDA	META PROJECTED (PHASE IV)
Number of IR Targets	2	24	10
Number of Laser Targets	2	43	20
Number of IR Backgrounds	0	38	20
Number of Backgrounds	2	169	20

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INPUT REQUIRED FOR LASER SUBMODELS

Submodel	Number of Input Parameters
Target Background	2
Transmissivity	12
Sensor Performance	9
Designator Range	3

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INPUT REQUIRED FOR INFRARED SUBMODELS

Submodel	Number of Input Parameters
Insolation	9
Sky Radiation	4
Target Contrast Model	16
Transmittance	12
Sensor Performance	11

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PHASE IV META INPUTS
Infrared Simulation

Target Type

Date, Time over Target, and Location

Orientation of Target (degrees)

Sensor ID

Sensor Height above ground level (kft)

Backgrounds

Sensor Field-of-View

Sensor View Direction (degrees)

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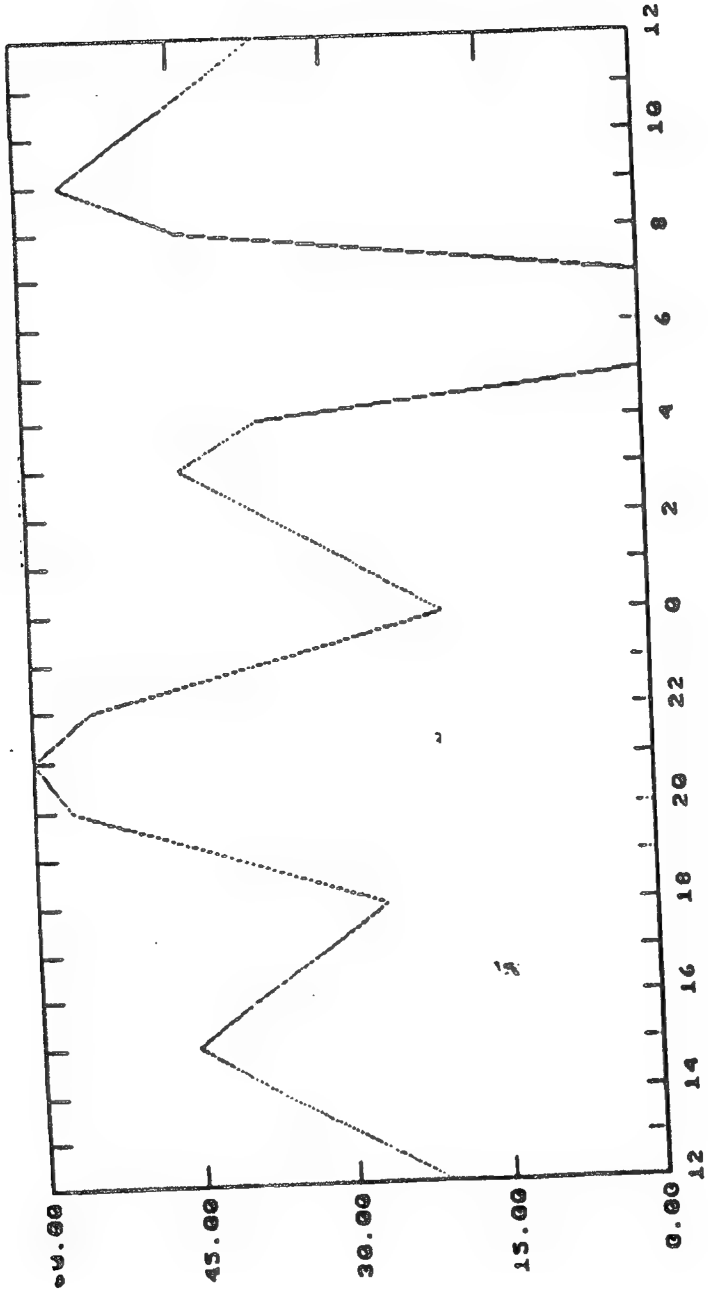
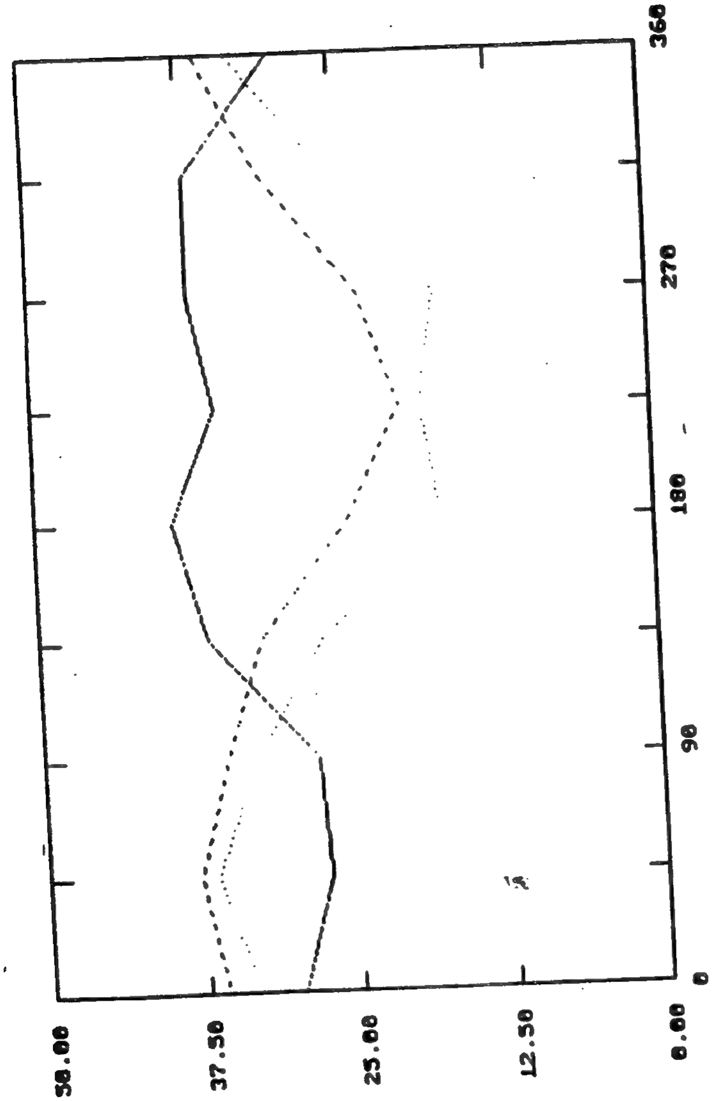

45.00
30.00
15.00
0.00
12
14
16
18
20
22
0
2
4
6
8
10
12



50.00
37.50
25.00
12.50
0.00
0
90
180
270
360

FINDINGS

- Twenty years of progress in EO research and modelling have been incorporated

- EO modelling strategies in META have been validated

- EO simulation and modelling are available through META to the training and operational communities

- "Bootstrapping" methods of modelling work just fine

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GOOD BOOTSTRAPPING TENETS

- Accept little data over no data
- Do not over invest in rigor and sophistication
- Temper patience with progress
- KISS (Keep it simple) always

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PHASE IV META INPUTS
Laser Simulation

Laser Mode

Date and Location

Target

Designator ID and Height (kft)

Receiver ID, Height (kft), and Range (kft)

Title of Plot

Greenwich Mean Time

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Simulation and Dynamic Analyses of Targets Using Standardized Modelling Techniques

by

Christos Pandelaras
Robert E Palmer

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ABSTRACT

The Navy has recently been expanding its dynamic modelling capabilities for analyzing targets. These capabilities include the analysis and evaluation of flight test results, as well as the prediction of vehicle dynamic characteristics for ensuring safe flights. In supporting real-time simulations, these models provide the capability to rapidly perform a wide range of dynamic analyses and sensitivity studies using standardized component modelling techniques. The engineering analysis package used for this modelling is EASY5, which is commercially available from Boeing Computer Services. EASY5 allows the user to utilize a generic model which was developed using pre-defined components such as lags, lead-lags, integrators, function generators, and switches to represent the vehicle's aerodynamic, propulsion, and control system characteristics. This paper covers: a) the way in which the models are developed, using either pre-defined components and/or user defined FORTRAN components, b) the ease of modifying control laws or performing sensitivity analyses, and c) the types of analyses available (steady state, simulation, transfer functions, root locus, etc). In addition, sample application cases to demonstrate the use and benefits achieved by using these modelling techniques in conjunction with real-time simulation for analyzing US Navy targets will be presented. In one case, without any control inputs, flight test data showed pitch and roll oscillations when the altitude hold control mode was turned on and off. This effect was indicative of a hysteresis or some other non-linear dynamic characteristic. Since the real-time simulation model developed by the contractor was expensive and time consuming to change, another quick and less expensive method was needed to verify the hysteresis effects. An existing model of a similar vehicle was modified to incorporate hysteresis effects in the actuator model. The flight test conditions were then simulated and the sensitivity to the hysteresis characteristics were examined. The results exhibited similar characteristics as the flight test in both the frequency and the damping of the oscillations for a representative hysteresis component. The contractor subsequently performed bench tests on the actuators/linkages and verified the existence of a hysteresis which he has since corrected.

Simulation and Dynamic Analyses of Targets Using Standardized Modelling Techniques

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INTRODUCTION

Current U.S. Navy targets have become very expensive to develop, flight test, and operate in realistic environments. As a result, significantly more emphasis is being placed on utilizing both real-time and batch simulation analyses to reduce these costs. These simulations provide an effective means to determine regions of unsafe flight prior to flight testing which minimizes the number of targets lost or destroyed. In addition, the number of flight tests required can be significantly reduced by utilizing these simulations to eliminate benign flight regions which do not need to be tested in flight. However, many target programs develop a variety of independent analytical models in order to support both hardware in the loop simulations and flight testing. Figure 1 illustrates the various models typically developed during this process. They include 3 Degree of Freedom (DOF) longitudinal, 3 DOF lateral/directional, and finally a full 6 DOF nonlinear model which provides an accurate characterization of all the dynamic components in the system. In most cases, these models are built up one at a time and then integrated with the hardware in the loop simulation and possibly checked out in flight tests. Although each of these models are important and provide their own unique information about the vehicles dynamics, they are usually developed individually which increases both the development time and cost.

Over the past ten years, the Flight Dynamics Branch at the Naval Air Development Center has been successfully modelling piloted aircraft using a different approach which has resulted in significant cost savings while providing comprehensive analysis capabilities. This approach has been to develop a full nonlinear 6 DOF model of the vehicle from the beginning using a commercially available computer code called EASY5 (Boeing Computer Services, reference (1)). The two primary reasons for starting with the most complex case first are: a) a nonlinear 6 DOF model will eventually have to be developed, and b) EASY5 provides the capability to extract the 3 DOF longitudinal and 3 DOF lateral/directional models with virtually no effort. Therefore, a significant amount of time can be saved since only one model has to be developed. Figure 2

illustrates this technique which we have used successfully to support flight dynamics analyses of aircraft such as the A-6, T-45, F-14, and others. Another benefit of using this approach is that EASY5 also contains a complete set of dynamic analyses capabilities such as parameter sensitivity studies, root locus diagrams, and the determination of transfer functions which can quickly and inexpensively be applied to specific problem investigations.

During the past two years the Flight Dynamics Branch, in support of our targets programs, has begun to apply this modelling technique to a number of existing targets including the BQM-34S, BQM-74C, and BQM-74E with good success. In one case, we identified a hysteresis effect in an actuator which prevented the vehicle from safely performing its mission. In another case, we have used our models to examine potential control law and engine modifications to the BQM-34S to determine what effect they might have on its flight dynamic characteristics prior to flight testing. We are convinced that this standardized modelling approach provides the Navy with the most effective analytical capability at the lowest cost. In the following sections we describe our development of this standardized dynamic model for targets using EASY5, the types of analyses that can be performed, and we provide more details concerning the use of these models in analyzing the two example cases mentioned above.

MODEL DEVELOPMENT

The modelling of a dynamic system in EASY5 is achieved using a modular approach. Pre-defined modules called "Standard Components" and user defined modules called "FORTRAN Components" serve as system descriptive building blocks. A module (component) depicts either: a) a specific analytical task such as the calculation of forces and moments in the longitudinal axis, b) a hardware function which simulates a single pole switch that can be used to describe a step or pulse input of a control surface, or c) standard block diagram elements such as a summer, lead-lag, or transfer function. Both types of components "Standard" and "FORTRAN" have specific inputs and outputs. Whether you describe your system using just "Standard" components or "FORTRAN" components, or a combination of both, the inputs and outputs of each component need to be properly connected to insure that the desired system has no implicit algebraic loops. When putting together a dynamic model of a target, or for that matter any air vehicle, the major elements that need to be described and connected in order to correctly simulate its motions are shown in Figure 3. These elements are unique to a given target and are: a) aerodynamic, engine, and control system tables, b) aerodynamic equations and description of the force and moment buildups, c) description of the engine characteristics, and d) description of the flight control system. EASY5 provides libraries of standard components that the user can use in the development of these

elements. Specifically, there are a set of standard components which were created especially for modelling aircraft dynamics. By using these components the user can quickly model the six degree-of-freedom bare airframe nonlinear dynamics of any aircraft or target. Figure 4 shows the schematic diagram of this bare airframe model using standard EASY5 components, including various inputs and outputs. The four standard components used are AV, LO, LD, and SD which are described below along with other commonly used components.

AV - Aerodynamic Variables Equations

Component AV uses the linear velocities, angular velocities, altitude, and Euler angles to compute aerodynamic variables such as dynamic pressure, angle of attack, angle of sideslip, and velocity.

LO, LD - Longitudinal and Lateral/Directional Force and Moment Equations

Components LO and LD combine the external forces and moments with the aerodynamic forces and moments in the body axis and output the total force components and moment vectors about the aircraft center of gravity. They also solve for the linear acceleration terms, in order to compute the implicit aerodynamic terms due to angle of attack and angle of sideslip rates.

SD - Six Degree-of-Freedom Rigid Body Dynamics

Component SD contains the rigid body dynamic equations for integrating the aircraft states. It is driven by the inputs of the aerodynamic variables computed by the LO and LD components.

FORTRAN - User Specified FORTRAN Code

As we know, existing targets come in many different shapes with many control surfaces that hardly resemble a conventional aircraft. To deal with these types of vehicles, the utilization of the user defined FORTRAN components becomes beneficial. Using FORTRAN components for computation of the forces and moments or for any other vehicle function, allows the user to make the model specific to the vehicle. Creating a FORTRAN component is very simple. Just as each standard component has a name (AV,LO,LD,SD), so does each FORTRAN component. All FORTRAN component names must start with the letters "FO" as shown in Figure 5. The next two characters in the name, for both standard and FORTRAN components, are used to distinguish between multiple occurrences of the same component in the model. The "LOCATION=" indicates the start of a new component, "FOAT" indicates that this is a FORTRAN component, while "INPUTS=",

"ADD VARIABLES=" represent the inputs and outputs of the component respectively. These statements are then followed by the "FORTRAN STATEMENTS" command and the FORTRAN code. For more detailed information on the formats and commands used the reader is referred to reference (1).

So far we have discussed the four major air vehicle standard components (AV,LO,LD,SD) and the use of FORTRAN components in developing a model. There are dozens more standard components and subroutines available to the user that can further assist in the development of the model. Not all of these standard components, subroutines, and techniques will be discussed here, but those most frequently used will be presented for the reader. One of these addresses the way in which tabular data is input and used in the model development. This is discussed in the next section.

FU, FV, and FW Table Look-up Subroutines

Most air vehicle models usually contain a number of data tables (aerodynamic tables, engine thrust and ram drag tables, control system gain schedule tables), that are needed to conduct a simulation. EASY5 provides the user with FORTRAN subroutines that can be used within FORTRAN components to perform table look-ups. The "FU" subroutine performs a one-dimensional look-up, the "FV" subroutine performs a two-dimensional look-up, while the "FW" subroutine performs a three-dimensional look-up. The largest table that can be accessed is nine dimensional and it is done through the "FN" subroutine. There are also standard components available that can perform the same functions. Figure 6 shows the call sequence that is needed to invoke the table look-up routines.

Once the processing of the entire system description is complete, the EASY5 program re-orders all the components, depending on the inputs and outputs of each component, to form an explicit model. It then translates it into an efficient FORTRAN code (an executable model) that can be reused for many different simulations and analyses without further processing. In other words, one model is used to perform all analysis. Figure 7 shows a block diagram of a control system along with an EASY5 schematic model representation of a dynamic system which illustrates many of the components discussed above.

ANALYSIS CAPABILITIES

Once an executable model has been generated, EASY5 allows the user to create an analysis file requesting the analyses to be performed. Before execution of these analyses, the specific model description must be completed by providing any numeric values for parameters (constants), tables, and initial conditions. This is

also accomplished in the analysis file. A sample analysis file requesting a steady state calculation and a simulation is shown in Figure 8. In this example, the analysis file consists of: a) a title description ("TITLE=EXAMPLE ANALYSIS FILE"), b) a command to define parameters ("PARAMETER VALUES"), c) a command to set up table values ("TABLE") to define the control input, d) definition of initial state values ("INITIAL CONDITIONS"), e) determination of trim condition ("STEADY STATE"), and f) the command to perform a simulation ("SIMULATE"). The parameter values and table commands are used to define all of the constants and table data specified in the model description. The initial conditions command is used to initialize all or some of the state variables in the model. Discussion of the steady state and simulate analysis, along with several other type of analysis is presented below.

Steady State Analysis

The steady state analysis is used to find an equilibrium (trim) point for the model. This point occurs when the root-mean-square value of all active system rates is near zero. The method used is a Newton-Raphson iterative approach, using knowledge of the system Jacobian, that algebraically manipulates the system states until the algorithm converges to a solution. This iterative process is repeated until either the norm of the rates becomes less than 0.0001 or the maximum number of iterations (e.g. in Figure 8 "SS ITERATIONS=40") has been reached. If, during the steady state analysis, a state causes the Jacobian matrix to become singular, that state will be frozen at its current value and the solution process will continue. In the example analysis file in Figure 8, the steady state command is solving for a trim solution of an air vehicle at a specified flight condition and configuration. Once this trim solution is reached, that operating point becomes the starting point for the simulation that follows by using the "XIC-X" command.

Simulation Analysis

Simulation analysis is the process of numerical integration of the model's equations of motion through time. It is used to generate time histories of the system outputs to evaluate the model's behavior. As shown in Table 1, there are a total of nine numerical integration techniques available in EASY5.

Name	Method	Order	Type
BCS Gear	BCS Modified Stiff Gear	Variable	Variable-Step/Implicit
Runge-Kutta	Variable-Step	4th	Variable-Step/Explicit
Runge-Kutta	Fixed-Step	4th	Fixed-Step/Explicit
Huen	Fixed-Step Huen Method	2nd	Fixed-Step/Implicit
Euler	Fixed-Step Euler	1st	Fixed-Step/Explicit
Adams	Adams-Bashforth Predictor Adams-Moulton Corrector	2nd-12th	Variable-Step/Explicit
Stiff Gear	Hindmarsh Version of Gear Algorithm	Variable	Variable-Step/Implicit
Linear Simulation	Linear Simulation	N/A	N/A
User-Defined	N/A	N/A	N/A

TABLE 1: Integration Methods

In the example analysis file in Figure 8, the integration method chosen was Runge-Kutta. There are also several other commands associated with the simulation analysis shown in Figure 8, and they are defined below:

TINC - is the integrator step size.
TMAX - is the maximum value of simulated time.
OUTRATE - is an integer number that is multiplied by the value of TINC to determine how often to record simulation data.
PRATE - defines how often you want output data printed.

Figure 9 is an example of a time history plot generated from the sample analysis file.

Transfer Function Analysis

The Transfer Function analysis is used to investigate the stability, performance, and frequency related response of the model. The analysis consists of two parts. First, the creation of

a linear model between two points in the system about the current operating point, followed by the calculation of the poles, the zeros, and the leading coefficient of the transfer function. Once these have been calculated, a frequency response analysis can be performed between the two specified points of the system. The frequency response function computed is the steady-state response of the linearized system to a sinusoidal input. This frequency response is calculated by evaluating the function over a range of frequencies which is either input manually or determined automatically. Three formats are available within EASY5 for plotting the results of a frequency response calculation. They are: Bode plot, Nichols chart, and Nyquist diagram. Figures 10, 11, and 12 are representative plots of each of these formats.

Root Locus Analysis

The Root Locus analysis calculates the loci of the system eigenvalues as a function of a specified parameter. The analysis can be performed as a function of any operating point value, or any system parameter. Since the analysis can be applied to both continuous and sampled data systems, the output can be given in either the s-plane or the z-plane. Before executing this analysis, the user needs to specify in the analysis file which quantity of the model to vary, through what range, and with what resolution. The commands used to do this are listed below:

RL PARAMETER - Root locus parameter name.
RL START - Initial value of root locus parameter.
RL STOP - Final value of root locus parameter.
RL POINTS - Number of points that make up root locus.

An example of a root locus plot that can be generated in EASY5 is shown in Figure 13 where the numbers inside the plot represent the value of the RL PARAMETER.

Eigenvalue Sensitivity Analysis

The Eigenvalue Sensitivity is another commonly used analysis which measures the sensitivity of the system eigenvalues to a change in a specified system parameter. The eigenvalue sensitivity measure is the ratio of the percentage change of each eigenvalue to the percentage change of the parameter for which the sensitivity is to be measured. To specify the eigen parameter in the analysis file, the following command is used:

EIGEN PARAMETER - Eigen parameter name.

To execute an eigenvalue sensitivity analysis, the following command is used.

EIGEN SENSITIVITY

The analysis capabilities presented in this section are only a portion of those available within the EASY5 program. In the next section, two example cases will be presented that apply some of these analysis capabilities to actual target vehicles. This was done in order to evaluate their dynamic response, or to predict their sensitivity to potential modifications.

APPLICATION CASES

As mentioned in previous sections of this paper, EASY5 dynamic analyses models of various targets have been, and are currently being developed at the Naval Air Development Center. These models utilize the approach of first developing a full 6 DOF nonlinear representation of the vehicle and then exercising the inherent capabilities of EASY5 to extract linear models, or to perform a variety of dynamic analyses. This section of the paper describes in more detail two recent applications of this approach. For these two examples, EASY5 models were used successfully to both evaluate and predict the dynamic response characteristics of target vehicles. In one case, it resulted in identifying a deficiency in the contractor design which was subsequently corrected at minimum cost to the Navy. In the second case, it is allowing the Navy to investigate potential changes to an existing vehicle prior to flight testing to determine their effectiveness. This will result in more efficient planning and conduct of flight tests of the vehicle when the modifications are implemented. These two examples are presented below.

Example #1:

In recent flight tests of an experimental target, whose dynamic characteristics are similar to those of a BQM-74C, unacceptable pitch and roll oscillations were observed. These were severe enough to prevent the vehicle from meeting its mission performance objectives. The oscillations occurred when the flight control system logic commanded the vehicle to enter an altitude hold mode. Immediately after this command was given, the vehicle started to pitch and roll as shown by Figures 14 and 15. The data presented in these figures have been extracted from actual stripcharts and were selected to illustrate the relative frequencies and amplitudes of these oscillations. As shown, both frequencies were approximately 0.75 cycles/second (cps) while the amplitude for pitch was 5.0 degrees and the amplitude for roll was 7.5 degrees. After examining these data in more detail, it appeared that a possible cause of these oscillations was the presence of nonlinear actuator dynamics typical of a hysteresis effect. In order to quickly determine whether this assessment was correct, an existing EASY5 model of the BQM-74C was modified within two days to include

a hysteresis component in the same control path as the actuator. This approach is shown schematically in Figure 16. Representative values of the hysteresis characteristics were then determined based on previous experience with other vehicles, and analysis conditions were set up to closely match the speed and altitude of the flight test data. A number of runs were then made to determine if the introduction of the hysteresis component would induce pitch and roll oscillations similar to those observed in the flight tests. Figures 17 (pitch) and 18 (roll) show the results of this analysis were very successful. In both these figures the baseline (no hysteresis) response of the BQM-74C, following a control input disturbance at 4.0 seconds, is shown for reference as a dashed line. The solid curve shows the response with the representative hysteresis effect. Both the pitch and roll responses closely matched the frequency and amplitude characteristics of the flight test data and supported the hypothesis that the actuators had some hysteresis. Prior to additional flight tests, the contractor's analyses were examined in more detail and it was determined that only linear actuator characteristics had been modelled. Based on a linear analysis, it was not surprising that the contractor had not predicted a hysteresis effect. Subsequently, the contractor conducted bench tests on the actuator to measure its dynamic characteristics and verified that hysteresis was present. Modifications to the actuator were then made and follow-on flight tests showed a significant improvement in the vehicle's pitch and roll responses in the altitude hold mode.

Example #2

The Navy has recently been investigating the impact of updating the flight control system in its BQM34S target from an analog system to a digital system, similar to the one that is currently in the Air Force's version of the target. The Naval Air Development Center has developed a dynamic simulation model of the BQM34S that incorporates this new flight control system. Some preliminary results are presented that demonstrate the type of predictive dynamic response analyses which can be performed with EASY5 before proceeding to flight testing. Two analysis were performed: a) a trim solution of the target was obtained at a nominal flight condition, and b) a longitudinal control input was applied to the bare airframe model. The flight condition used for this analysis was:

Mach = 0.6
Altitude = 10,000 feet
Weight = 2100 pounds
Center of Gravity (C.G.) = 25% Mean Aerodynamic Chord(MAC)

Using the "STEADY STATE" command the target was trimmed at this flight condition. The trim solution showed the target trimming to an angle-of-attack (ALPHA) of 2.817 degrees (Figure 19a), with a

...tor deflection (DSTAB) of -4.912 degrees (Figure 19b), and ...st (PNET) equal to 471.64 lbs. A "SIMULATE" command was then ...d to simulate a few seconds at this trim point, to assure that ... target stayed trimmed. We next applied a stabilator doublet to ... bare airframe model at this trim point, using a "TABLE" command ... the analysis file, to observe the longitudinal response of the ...stem. Figure 20a and 20b show that for the stabilator input ...plied, the target behaved in the manner that was expected. That ..., for a negative stabilator deflection (trailing edge up), the ...gle-of-attack increased, the airspeed decreased, and the altitude ...creased.

...onclusions and Recommendations

...he standardized modelling approach described in this paper, ...s... EASY5, has proven to be a very powerful and cost effective ...ethod for studying the dynamic characteristics of U.S. Navy ...targets. This approach develops only one analytical model (6 DOF ...nonlinear) which can be used to perform a wide range of dynamic analyses. These include sensitivity studies of specific model parameters, automatic extraction of linearized models, determination of trim conditions, batch simulation, and parameter optimization to name a few. Another benefit to this approach is that the majority of the model can be used from vehicle to vehicle since many of the components are standardized, such as those used to define the equations of motion. The only sections that need to be changed are the aerodynamic force and moment buildup, control system, and engine characteristics. These can usually be extracted from real time hardware-in-the-loop simulations in FORTRAN, or they can be modelled within EASY5 using standard components. In either ...se, this approach provides a comprehensive analysis capability ...at is low cost, quick to develop, easy to adapt to any target, and which augments real time simulation. It is recommended that this modelling approach be expanded to other U.S. Navy targets in order to provide the analysis capability required to develop safer, more operationally effective, and less expensive targets.

REFERENCES

(1) "MAINSTREAM - EKS Programmer's Manual, EASY5 Dynamic Analysis System User's Guide," BCS Document 10208-001-R1.

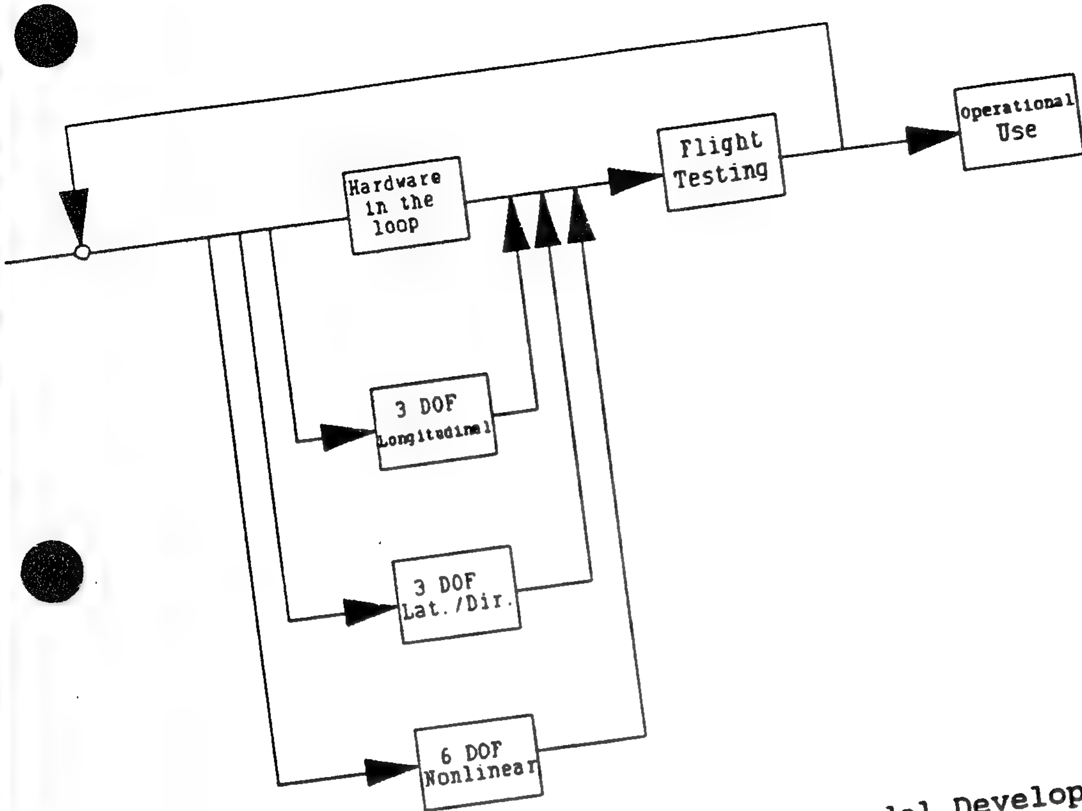


FIGURE 1: Conventional Approach to Dynamic Model Development.

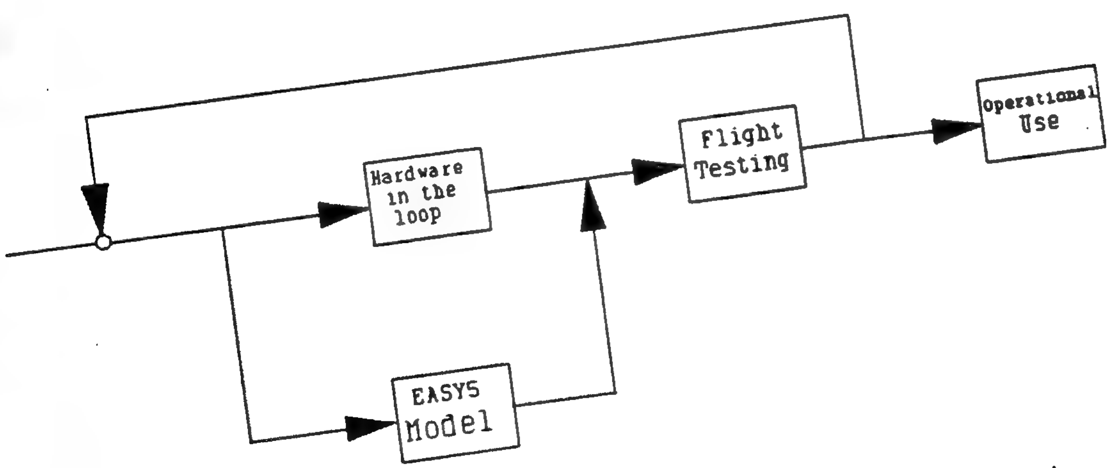


FIGURE 2: Modified Approach to Dynamic Model Development.

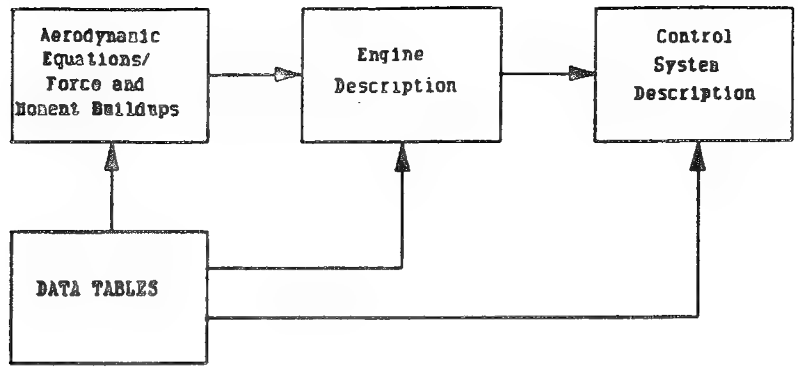


FIGURE 3: The major elements associated with the development of an air vehicle dynamic model.

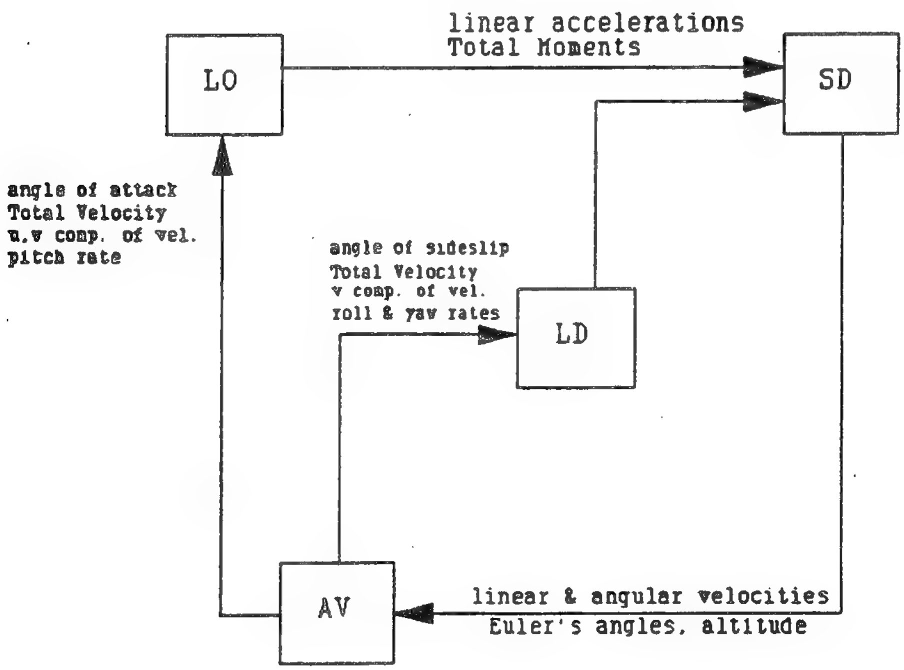


FIGURE 4: Bare airframe schematic diagram using air vehicle standard components.

```
LOCATION=259    FOAT    INPUTS=QC AV,W  SD,EA SD,DEF2AIL
*
ADD VARIABLES=AKP,RADW1,RADEA1
*
FORTRAN STATEMENTS
*
        IF (QC AV .LT. 100.) AKP = 1.0
        IF (QC AV .LT. 100.) GOTO 500
        AKP = 96.64/QC AV + 0.0334
  500   RADW1 = W  SD(1)/57.3
        RADEA1 = EA SD(1)/57.3
*
```

FIGURE 5: Example of a FORTRAN component as defined in batch model.

```
CALL FU(tn,dv,idv1,an1)

CALL FV(tn,dv,idv1,idv2,an1,an2)

CALL FW(tn,dv,idv1,idv2,idv3,an1,an2,an3)
```

where:

tn is the look-up data table name
dv is the output (the table-dependent variable)
idv1 is an input (the first-table independent variable)
idv2 is an input (the second-table independent variable)
idv3 is an input (the third-table independent variable)
an1 is an extrapolation flag for **idv1** (any negative real value will prevent extrapolation)
an2 is an extrapolation flag for **idv2** (any negative real value will prevent extrapolation)
an3 is an extrapolation flag for **idv3** (any negative real value will prevent extrapolation)

FIGURE 6: Call sequences and argument definitions for table look-up subroutines.

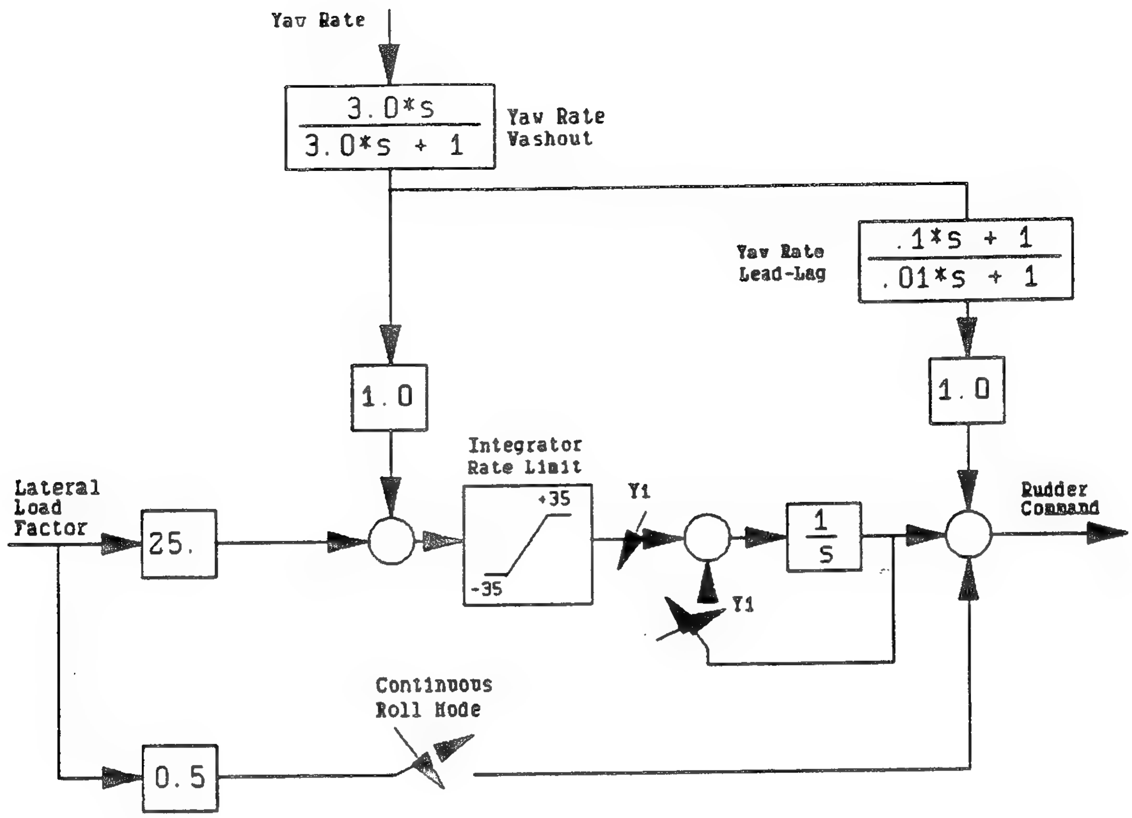


Figure 7: a) Block diagram of air vehicle control system.

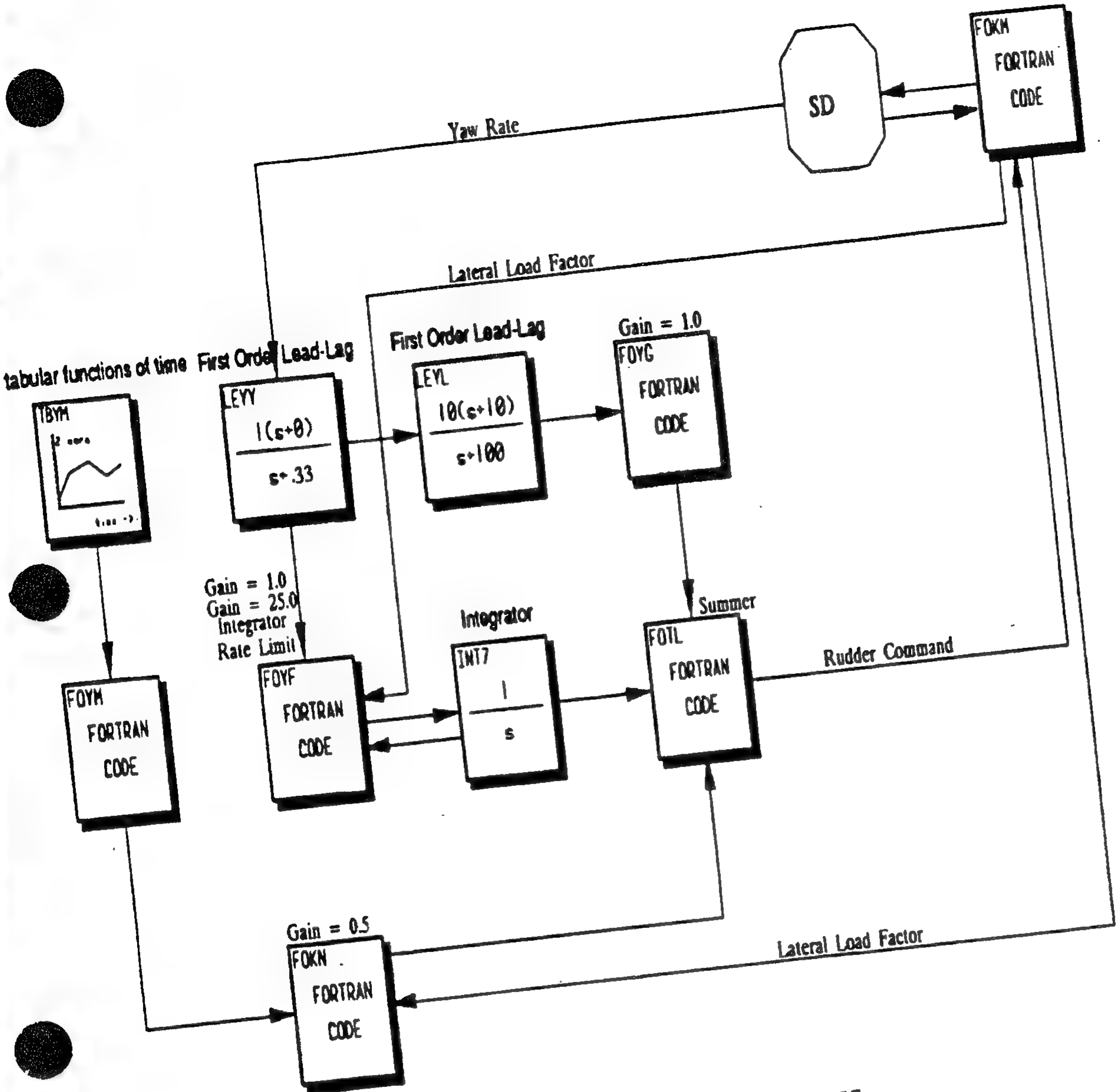


Figure 7: b) Schematic representation of control system in EASY5.

```
TITLE=EXAMPLE ANALYSIS FILE
*
PARAMETER VALUES
  S=179.64          CBAR=5.83          SPAN=30.8
  GW=11500.0        FSREF=258.47       FSCG=254.972
  WLREF=28.46       WLCG=27.61         FLAP=50.0
  SLAT=15.0
*
TABLE, A2TTBFP, 8
0.0, 0.99, 1.0, 1.01, 3.0, 3.01, 5.0, 10.0
0.0, 0.0, 15.0, 15.0, 15.0, 0.0, 0.0, 0.0
*
INITIAL CONDITIONS
  U  SD(1)=222.6  U  SD(2)=0.        U  SD(3)=11.666
  W  SD(1)=0.     W  SD(2)=0.        W  SD(3)=0.
  EA SD(1)=0.     EA SD(2)=3.0       EA SD(3)=0.
  ALTSD=500.0
*
SS ITERATIONS=40
STEADY STATE
*
XIC=X
*
INT MODE = RUNGE KUTTA
TINC=0.01,   TMAX=10.0,   OUTRATE=1,   PRATE=1
SIMULATE
*
```

FIGURE 8: Example of an analysis file in EASY5 batch mode.

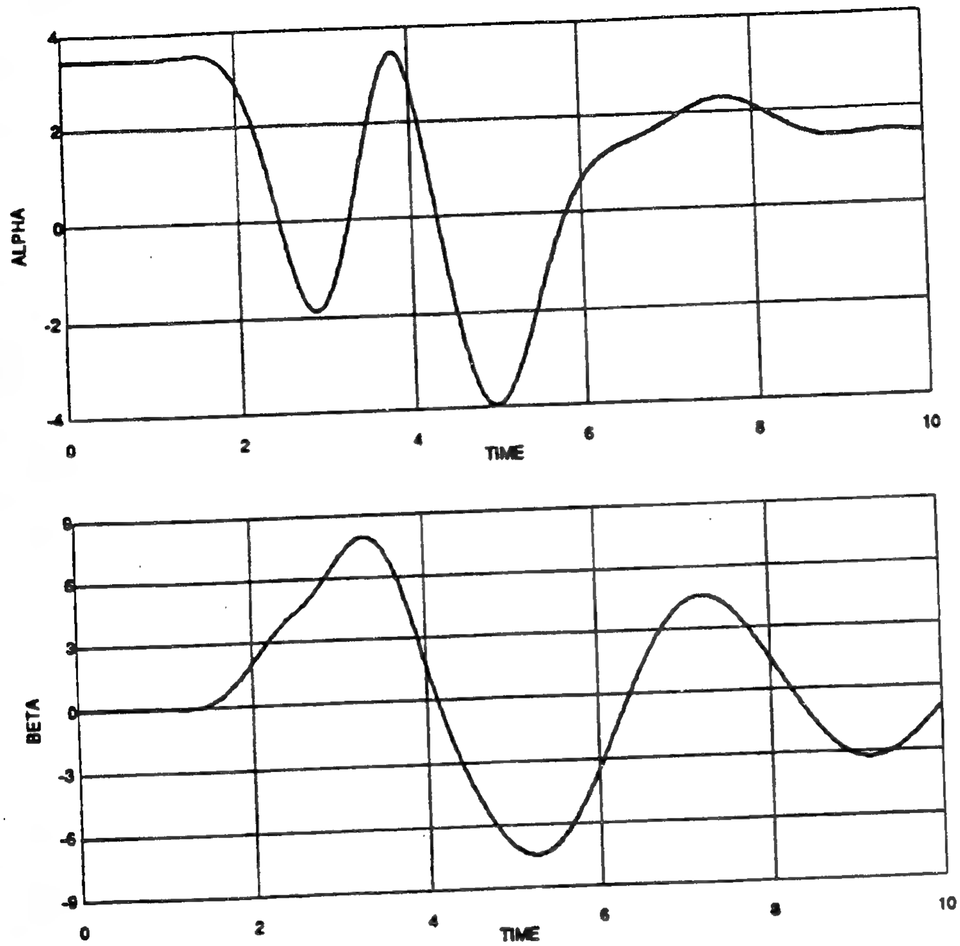


Figure 9: Example of a time history plot

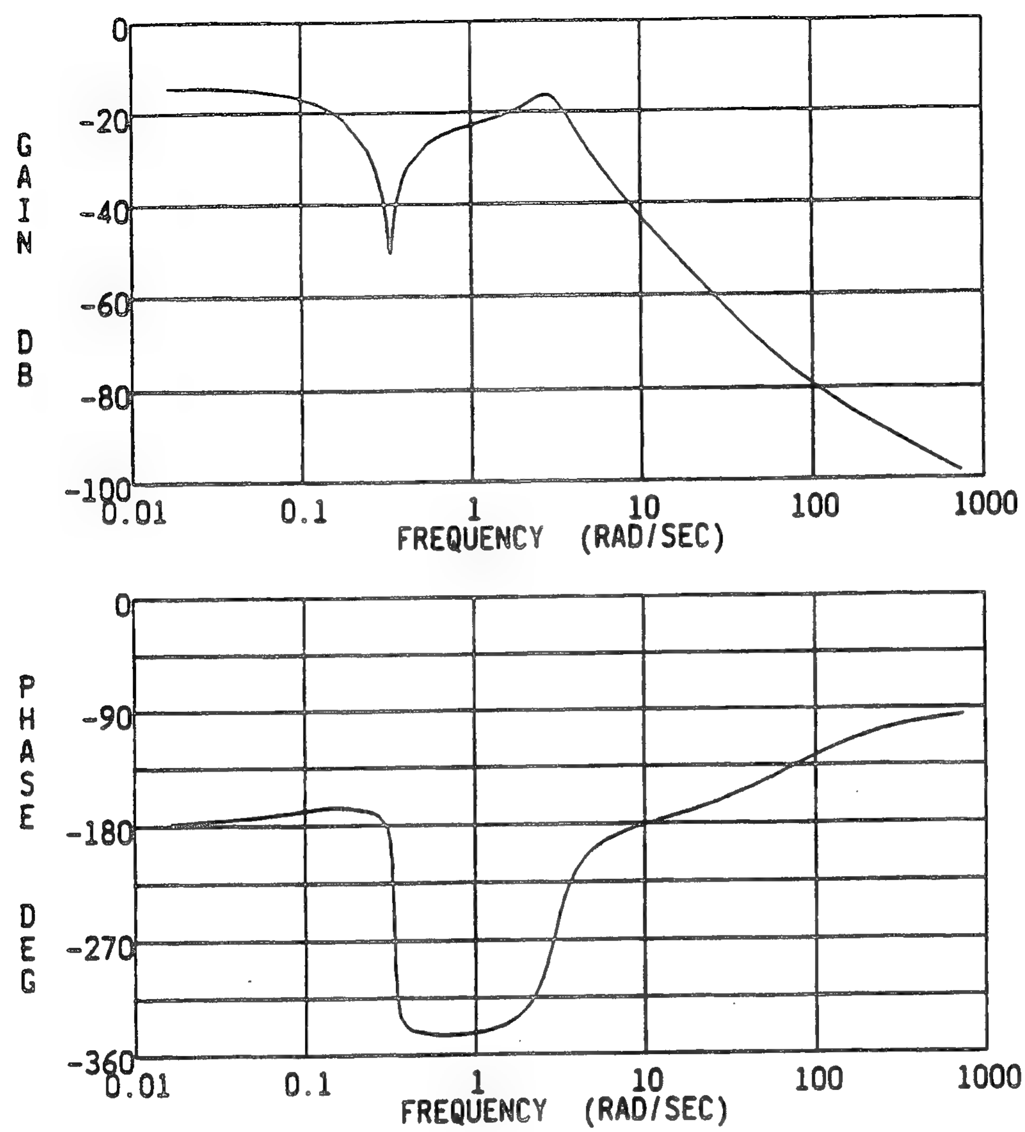


Figure 10: Example of a Bode plot.

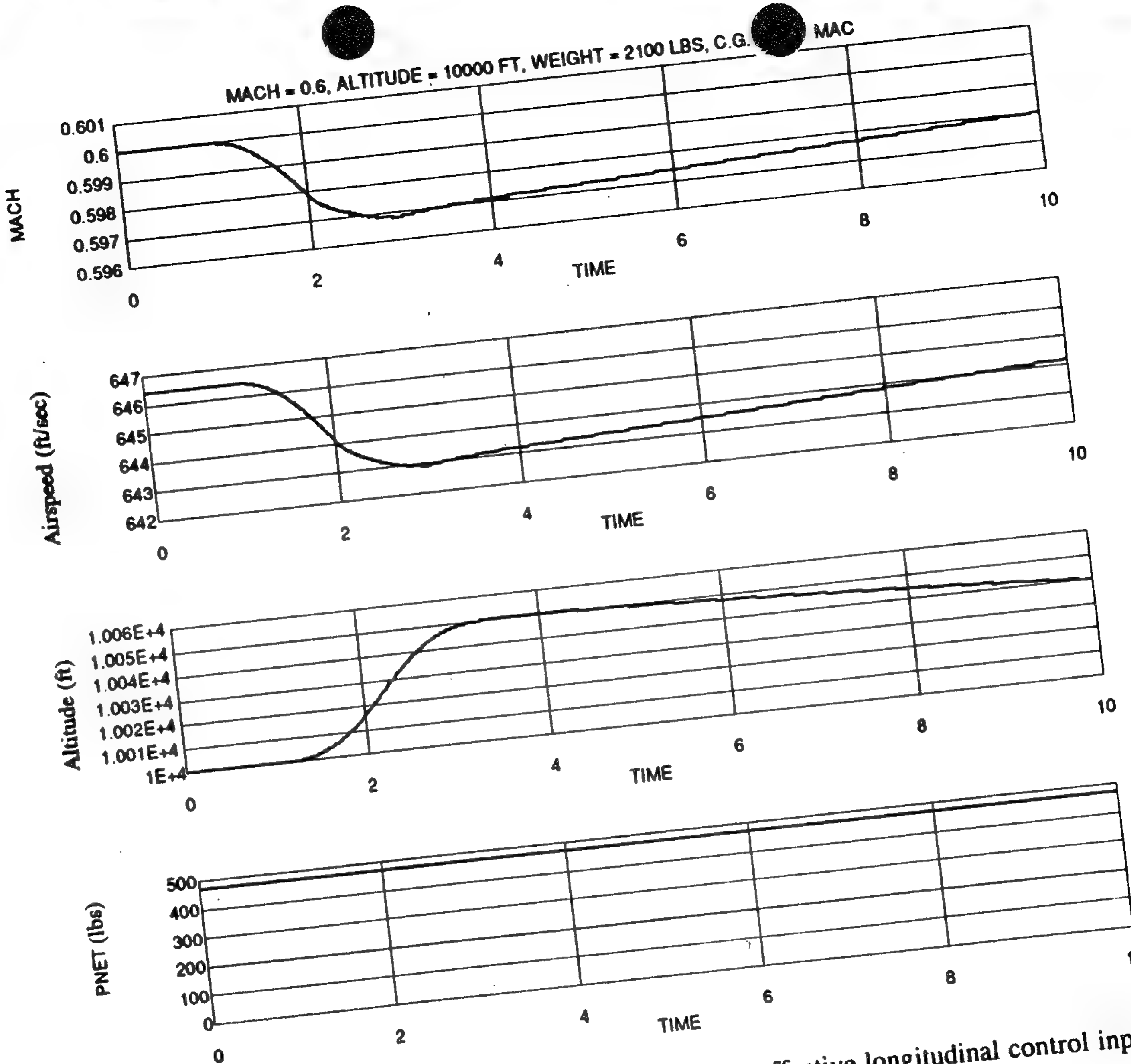


Figure 20: b) Response of bare airframe model to effective longitudinal control input.

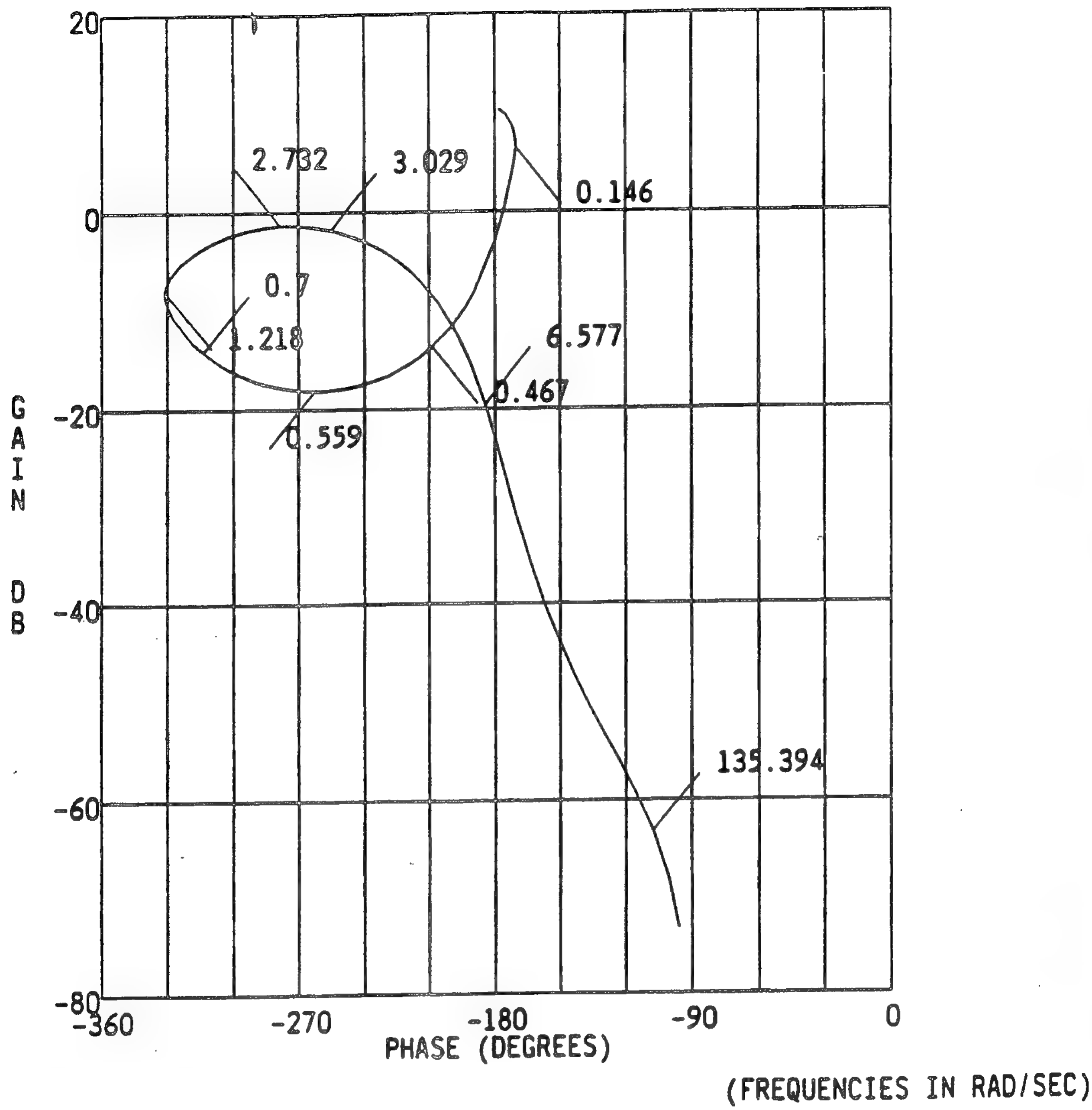


Figure 11: Example of a Nichols chart.

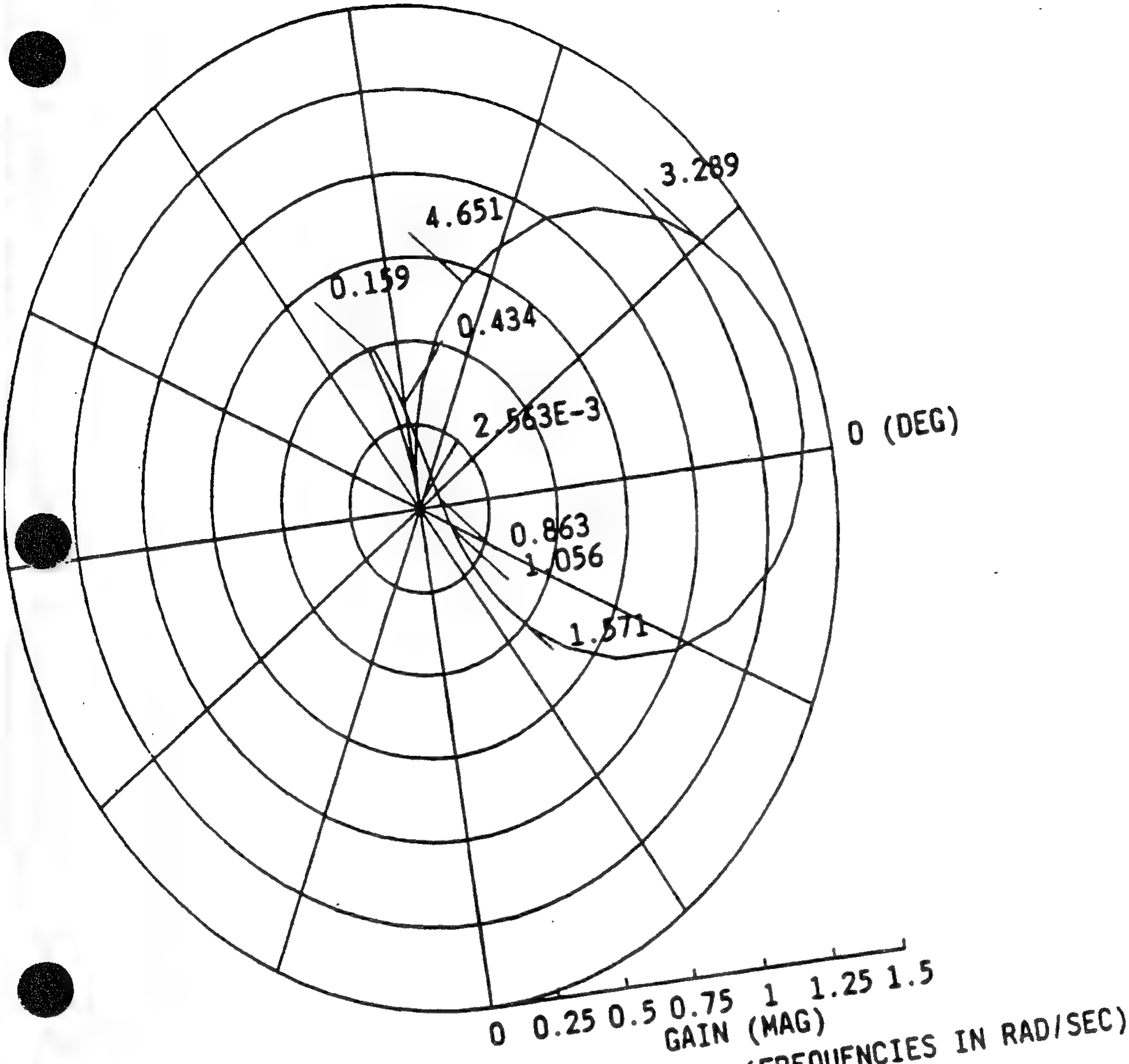


Figure 12: Example of a Nyquist diagram.

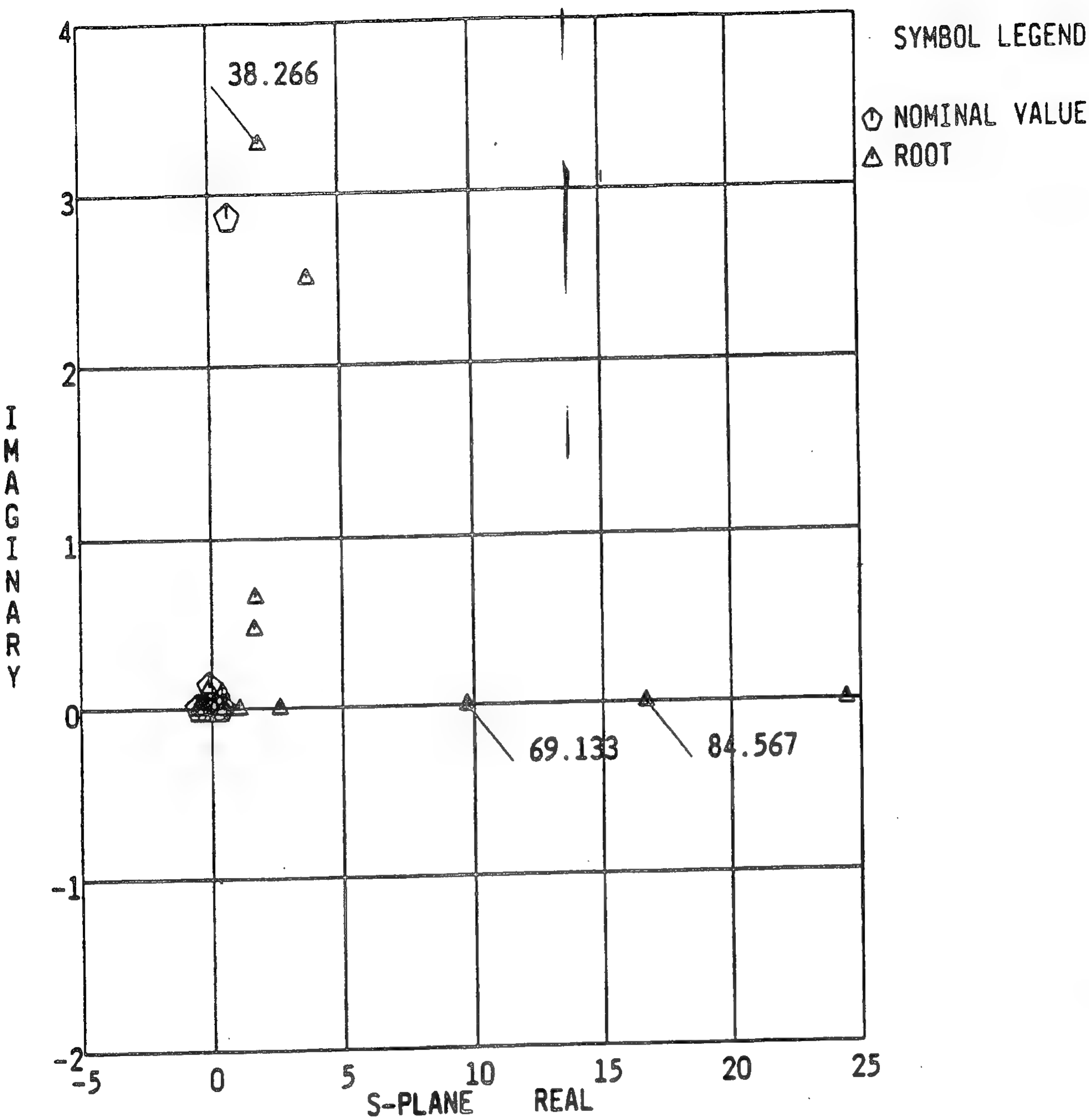


Figure 13: Example of a Root Locus plot.

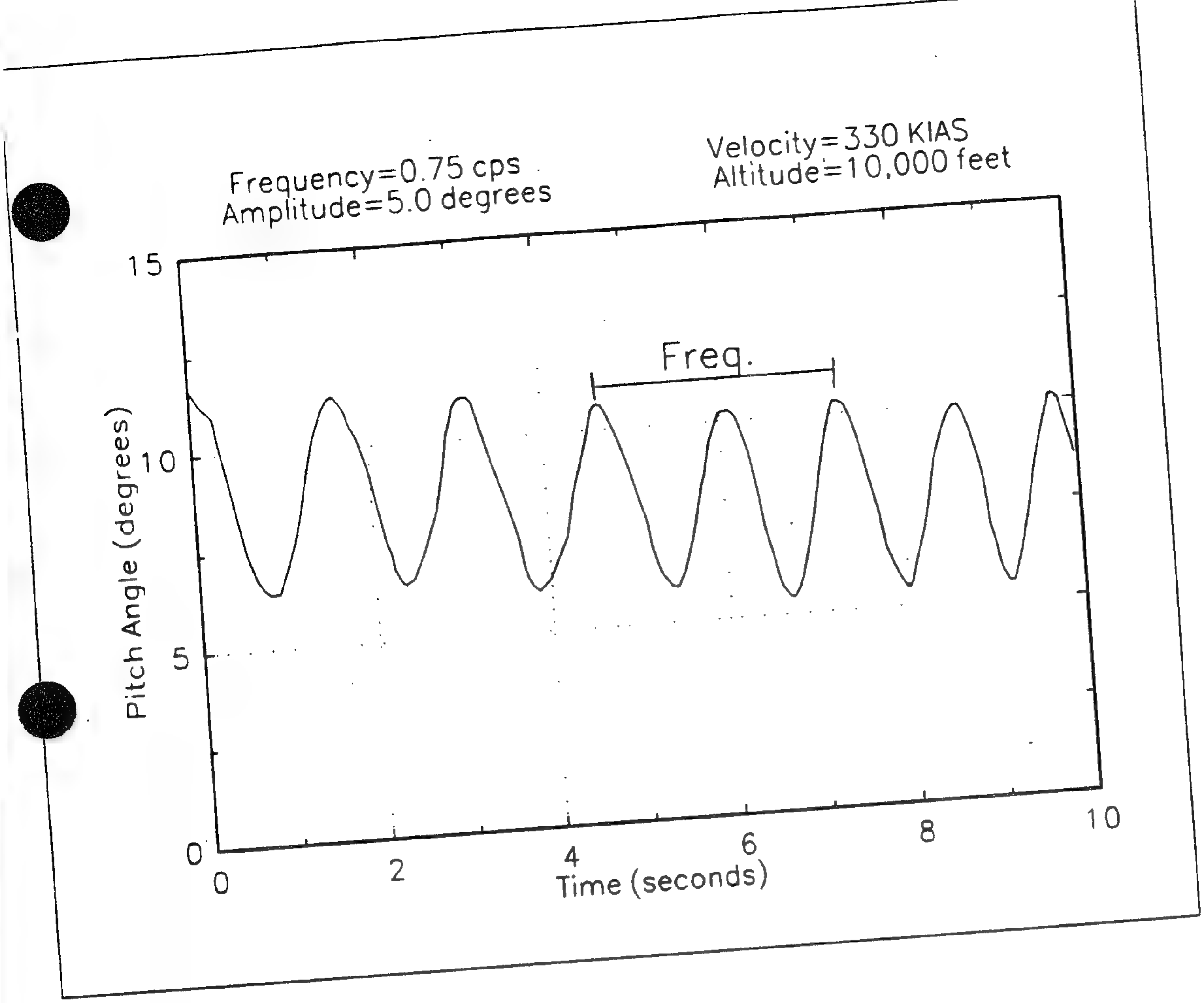


Figure 14: Flight Test Data Results - Pitch Response.

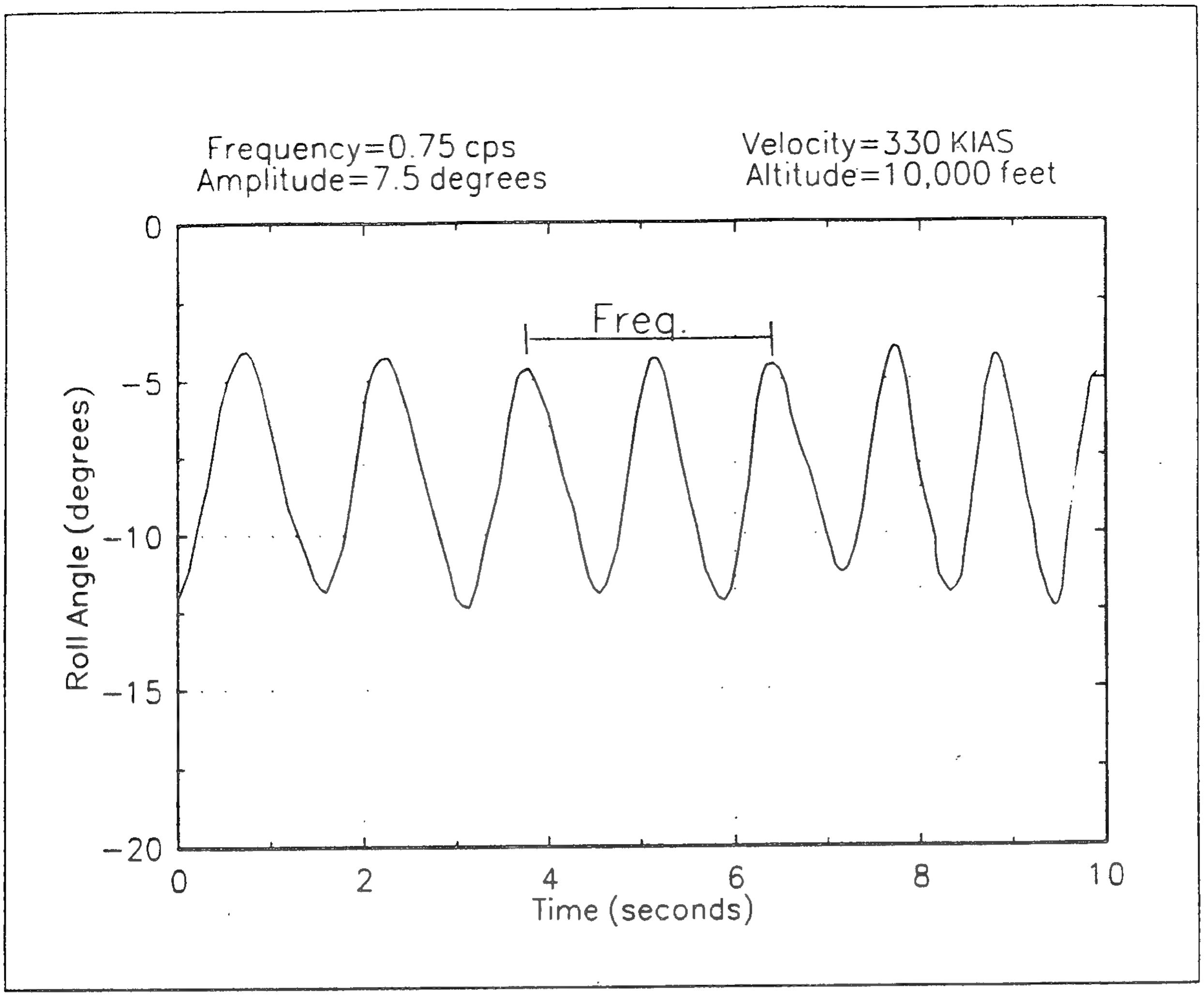


Figure 15: Flight Test Data Results - Roll Response.

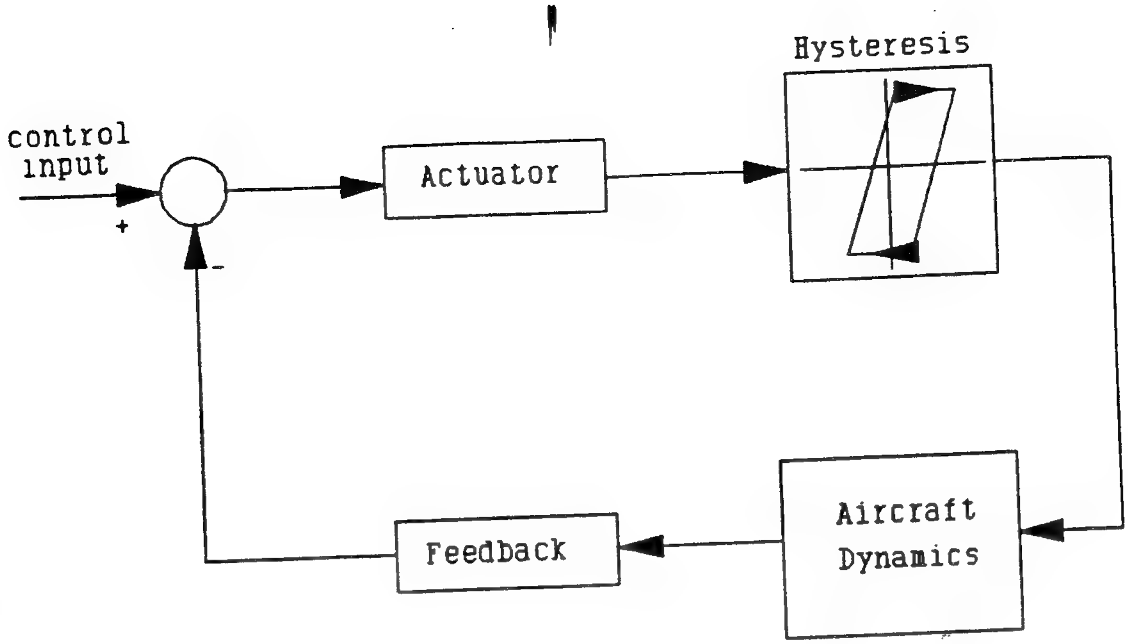


Figure 16: Modified BQM-74C EASY5 Dynamic Model.

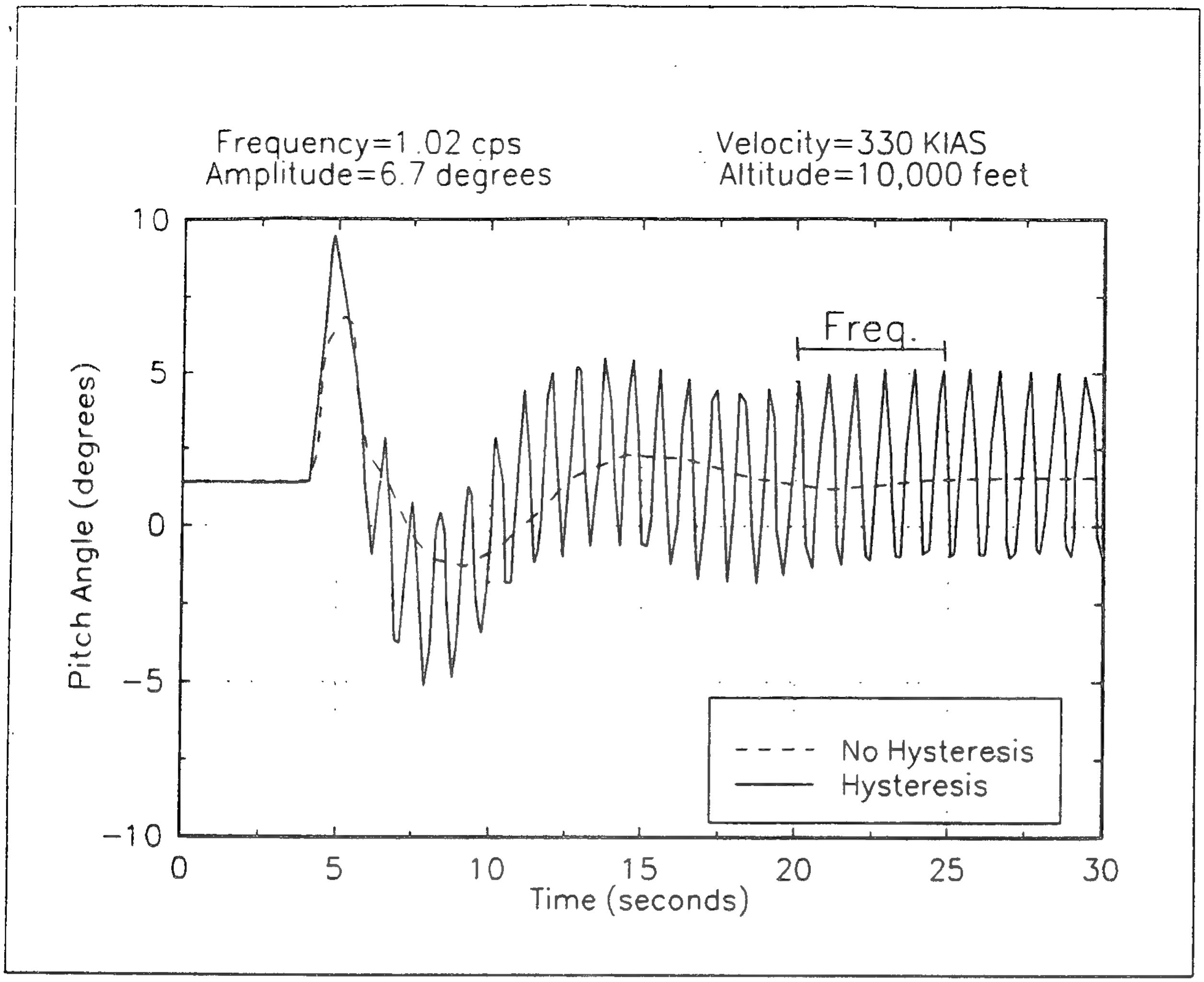


Figure 17: EASY5 Results for Pitch Response.

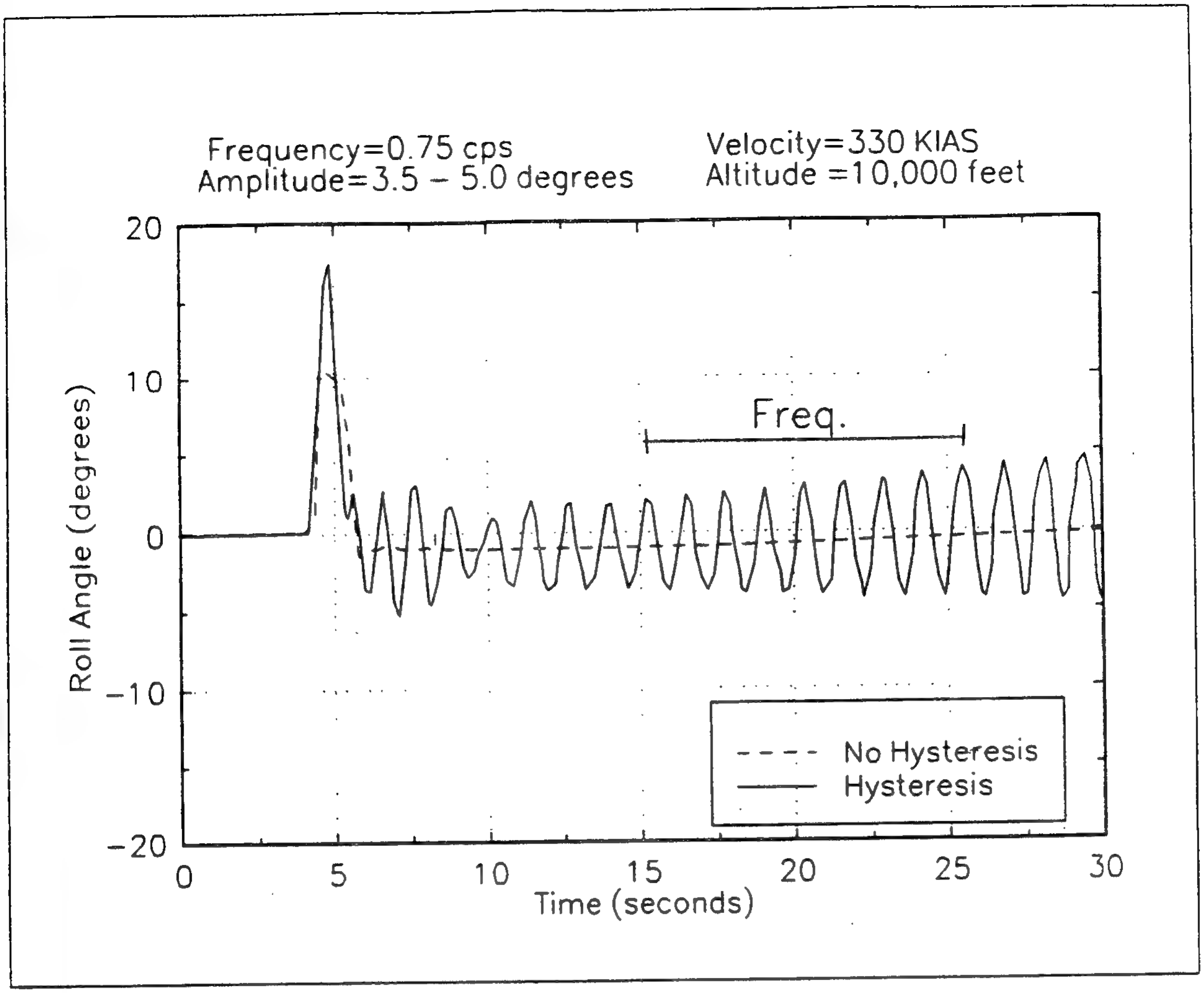


Figure 18: **EASY5 Results for Roll Response.**

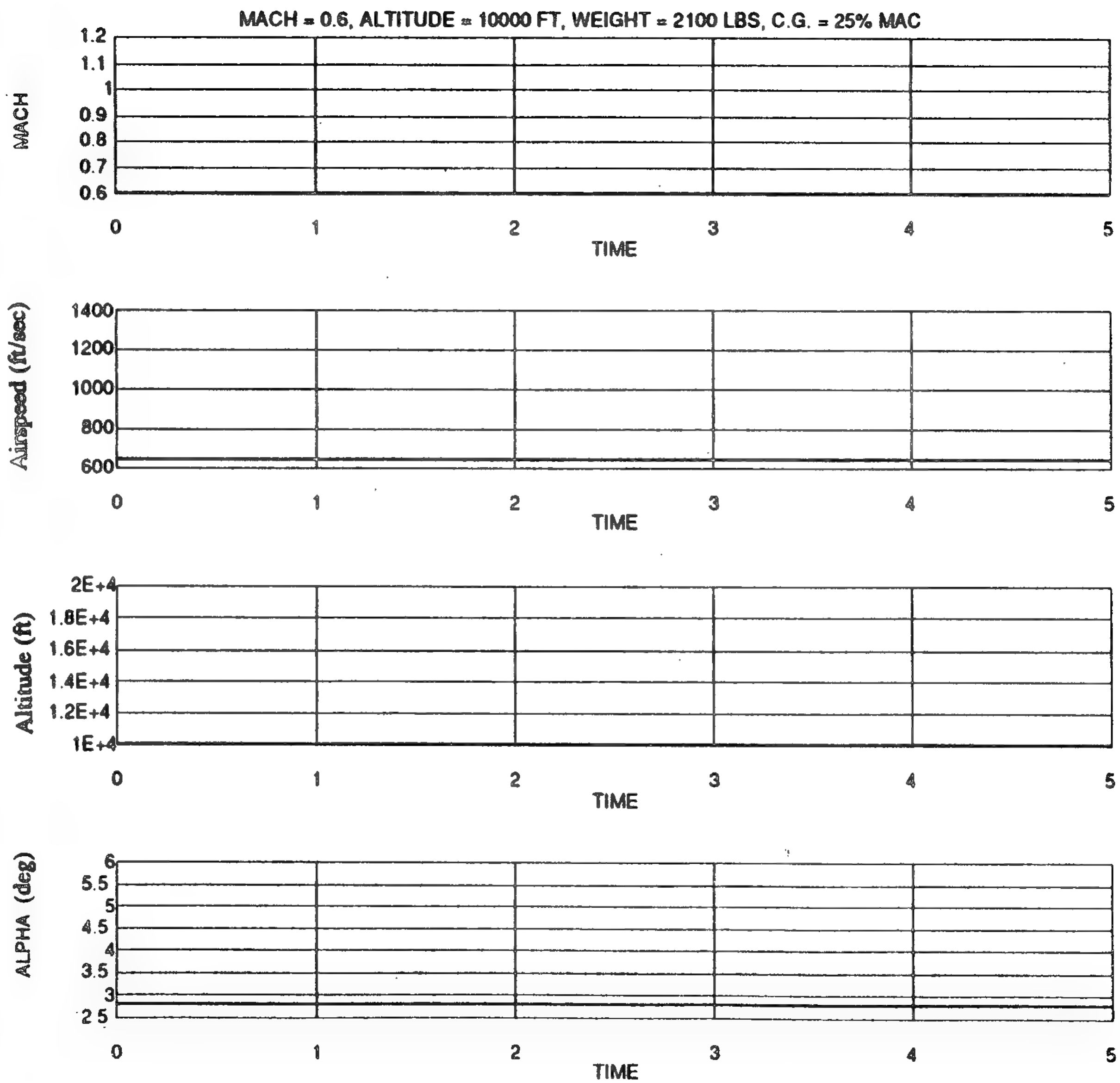


Figure 19: a) Trim solution at nominal flight condition.

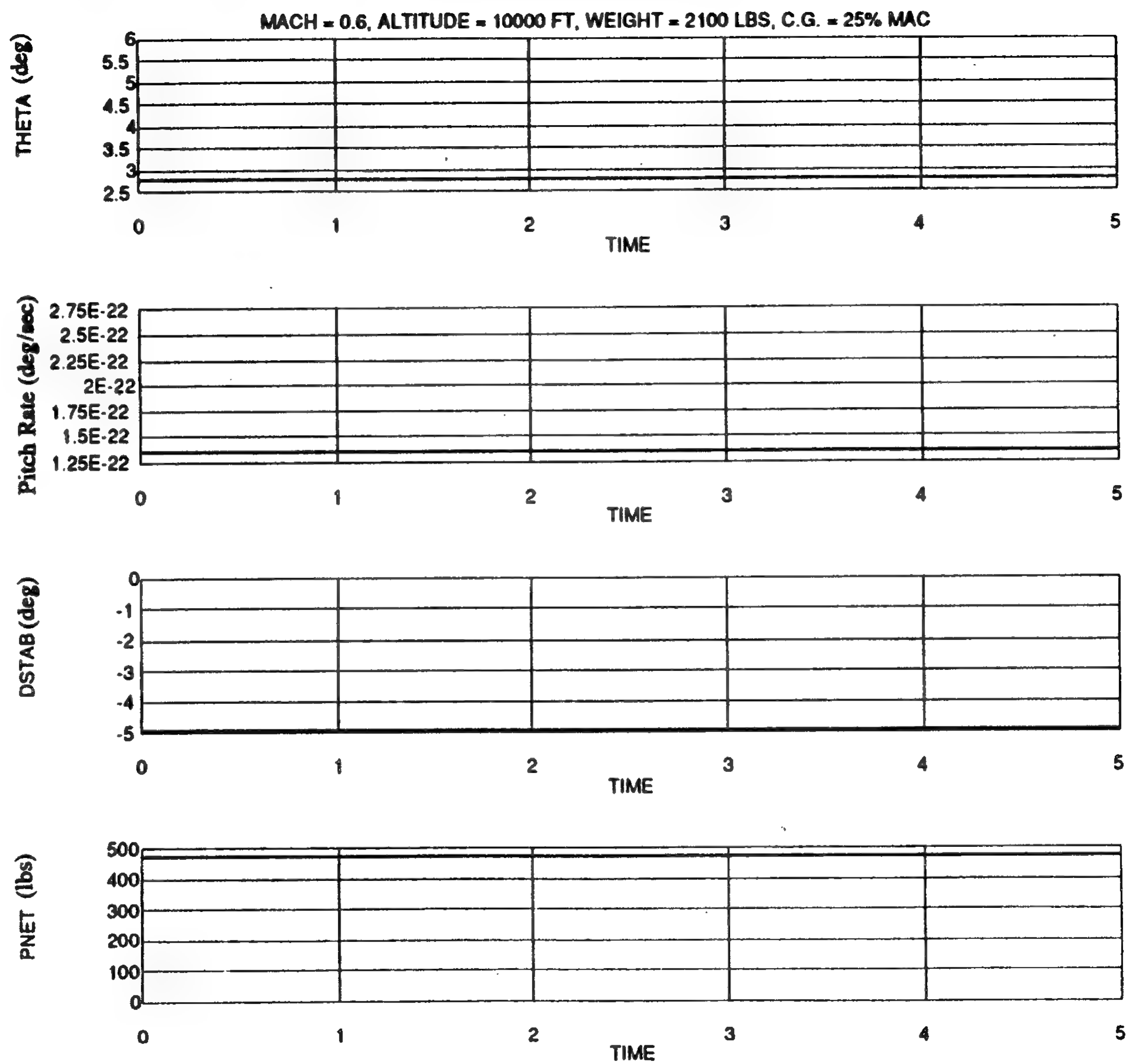


Figure 19: b) Trim solution at nominal flight condition.

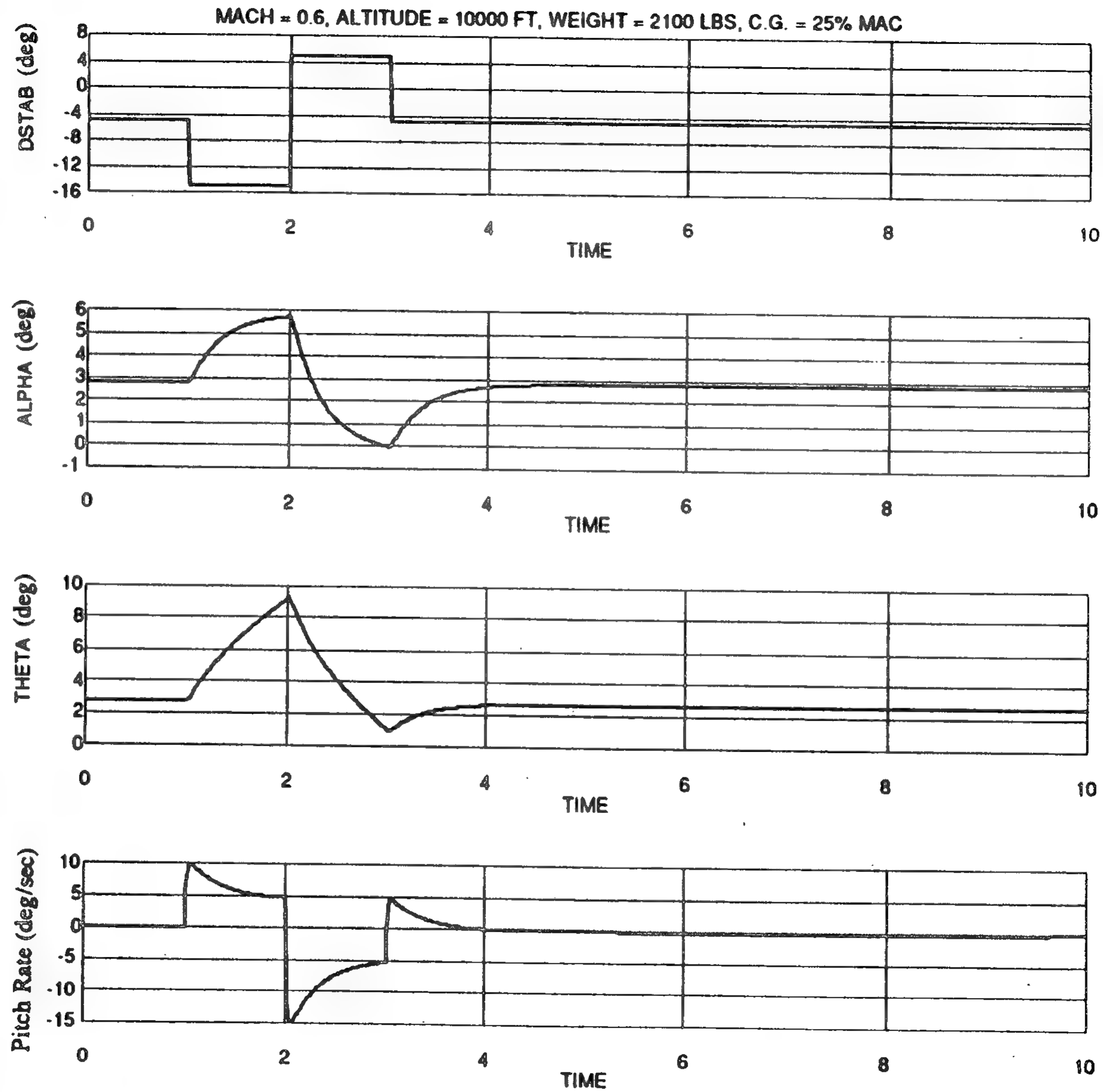


Figure 20: a) Response of bare airframe model to effective longitudinal control input.

LOW COST RECONFIGURABLE COCKPIT FOR TACTICS/TEAM TRAINING

Richard A. Weeks, *SYMVIONICS, Inc.*
Thomas C. Kopke, Naval Training Systems Center

Abstract

The Naval Training Systems Center (NTSC) awarded a Small Business Innovative Research (SBIR) Phase I contract to *SYMVIONICS, Inc.*, to perform a design study of a economical reconfigurable deployable cockpit for flight and tactics simulation and training (also referred to as the Low-Cost Reconfigurable Cockpit or LCRC). The basic requirement was simple: Design a low cost deployable, reconfigurable, self contained, and high fidelity cockpit for use in a training system. The eventual deployed system would consist of the cockpit module, an out-the-window display (one or more window displays or a helmet mounted display) with an accompanying image generation system, and an instructor/operator terminal. All other hardware/software required for the simulation would be self contained within the cockpit module.

The LCRC architecture provides for both the cockpit simulation, as well as the underlying weapon system simulations. Therefore, a stand-alone operations capability of the LCRC is attained. The LCRC utilizes a carefully-planned network of embedded processors within modules which represent "sections" of the cockpit. These modules are then installed on a base structure which is common to all cockpits. The base provides all necessary services to activate the cockpit, such as power, computer network interfaces, video interfaces and cooling.

Background

Aircraft simulation and training for the military play an essential role to increased pilot safety and mission effectiveness. Today's complex military aircraft dictate that pilots have continuous exposure to their aircraft to maintain skill proficiency. In today's environment of shrinking budgets, the need for simulation availability has not lessened. In fact, there is a shortage of simulation systems. With less money to spend on simulation hardware, the need for systems to have more commonality increases. The commonality would minimize duplication of systems, which in turn would save fiscal resources. One example of the commonality of systems is demonstrated by project 2851. The objective of this project is to create a standard data base format for use in computer-generated sensor/visual imagery. This would allow for data bases to be transported from one system to another, thus eliminating duplicate data bases for different imaging systems.

A flight simulator normally uses components that are specific for the given simulated vehicle. For example, if the simulator was designed to simulate the environment of a F/A-18, one could not use the simulator for A-6 simulation. However, by changing the simulation software and cockpit structure, the same simulation equipment could be used to simulate any aircraft desired. One could also just change the interior components of a cockpit shell to simulate a family of aircraft. This reconfigurable cockpit would allow simulation and training for a group of different platforms in a little more space that a single simulator takes.

A reconfigurable cockpit would increase the utilization capability of simulators. However, because of the shortage of available simulators, simulator use is usually 24 hours a day and an added aircraft simulation capability to a platform would add no value. A reconfigurable cockpit with built-in computational hardware would have value if it could be deployed to sites where simulators are not available. These candidate sites would most likely have a small number of users for a given airframe making it impractical to have a single aircraft simulator stationed. A reconfigurable cockpit would allow for multiple platforms thus increasing utilization of the simulation assets to full potential. A deployable reconfigurable cockpit would make available simulation in areas that are space restricted and/or temporary stations.

With the recent advances in technology, the cost of a flight simulator ten years ago can be built today for a fraction of that previous cost. Improvements in technology have made available greatly increased fidelity and simulator capability. Technology now allows for a high fidelity simulation environment at a reduced cost. To apply the latest in reduced cost simulation technology to the deployable, reconfigurable cockpit would increase the access to simulators by allowing multiple procurements of the reconfigurable cockpits for the price of one. Of course the low cost systems would not have all the features as the current fixed site simulators but would have partial capability at least to maintain pilot skills while away from conventional training sites.

Reconfigurable Cockpit Alternatives

As with any classical System Engineering design, a top-level trade-off analysis of approaches was conducted. This analysis was conducted early during the Phase I effort, in order to establish a clear direction for all subsequent design activities to proceed. *SYMVIONICS* addressed three fundamental approaches to providing a variety of cockpit simulations (i.e., different cockpits), which could be used for tactics team training. These approaches were as follows:

- Option 1: Electronic replication (and reconfiguration) of crew system Controls and Displays
- Option 2: Interchangeable cockpits (in their entirety)

- Option 3: Interchangeable individual cockpit Control and Display modules

The various reconfigurable cockpit options were evaluated or scored as alternatives against a set of weighted criteria, based on a formalized, classical, system engineering trade study methodology. Classical trade study analysis establishes concise alternatives to a problem, which are evaluated against concise criteria; based on relative, established (apriori) procedures. Alternatives were scored based on the "goodness" of the alternative Criteria used in the evaluation included: Fidelity, cost, ease of reconfigurability, logistics (storage space and number of people to reconfigure cockpit), reliability, maintainability, training effectiveness and customer preference.

The first approach, electronic replication (and reconfiguration) of crew system Controls and Displays, is created using the so-called Virtual Cockpit concept. With this concept, the cockpit "panel space" is replaced with electronic display devices, such as CRTs. These displays then become output devices for high-resolution graphics generators. The graphics generators create a facsimile or graphics rendering of the various cockpit Controls and Displays. The display devices are then overlaid with a touch sensitive "screen" such that crew inputs (switch actions) are accomplished by touching the appropriate control element. Appropriate cockpit display responses are then reflected by changes in the graphics displays.

The second approach examined was a self-contained interchangeable cockpit (entire cockpit), representing the various aircraft, to be interchanged. This approach allows for each cockpit to be internally wired to its unique configuration. This internal wiring is then interfaced with a centralized on-board cockpit processor, such that a vast amount of cockpit Control and Display processing can be done locally at the cockpit, relieving this burden from the simulator host computer system.

The third approach, interchangeable individual cockpit modules (with embedded processors), allows for major sections of the cockpit to be physically relocated within a common cockpit structure. With this approach, individual displays, control panels, side consoles, etc. are identified for each aircraft cockpit to be represented in the training system. A common cockpit base structure, for these various aircraft cockpits, is then created in which these removable and replaceable cockpit modules are placed. Therefore, depending on the particular configuration of the cockpit to be used in the team trainer, various modules are either removed, installed or rearranged in this common cockpit structure.

Table 1 depicts a summary of the advantages and disadvantages of each alternative option, as it relates to the requirements of this research activity.

METHOD	ADVANTAGES	DISADVANTAGES
ELECTRONIC REPLICATION AND RECONFIGURATION ("VIRTUAL COCKPIT")	• SHORT TIME TO RECONFIGURE COCKPIT CONTROL AND DISPLAY ARRANGEMENT • RECONFIGURATION IS ACCOMPLISHED BY LOADING NEW SOFTWARE, REFLECTING A GRAPHICAL RENDITION OF THE COCKPIT PANEL • ESPECIALLY USEFUL DURING COCKPIT CONTROLS & DISPLAYS DESIGN	• LOSS OF FIDELITY PARTICULARLY WITH RESPECT TO TACTILE FEEL AND THE REPRESENTATION OF THE ELECTRONIC HEAD-DOWN DISPLAYS • POTENTIAL FOR A NEGATIVE TRANSFER OF TRAINING • COCKPIT GEOMETRIES MAY BE VIOLATED, FURTHER AUGMENTING THE LOSS OF TRAINING FIDELITY AND CAPABILITY • DISPLAY LIMITATIONS MAY LIMIT THE AMOUNT OF COCKPIT PANEL SPACE WHICH CAN BE DEPICTED (LIKE SIDE CONSOLES)
INTERCHANGEABLE COCKPITS OF ENTIRE COCKPITS	• ENHANCED REALISM AND FIDELITY OF THE COCKPIT • EACH COCKPIT IS BUILT TO THE EXACT SPECIFICATION OF THE ACTUAL SYSTEM • MOLD LINES, PANEL GEOMETRY AND CONSOLE CONFIGURATIONS ARE ACCURATELY REPLICATED • THERE IS A DRAMATIC REDUCTION OF COMPLICATED EXTERNAL INTERFACES TO THE SIMULATOR HOST COMPUTER SYSTEM (NO INTERNAL COCKPIT WIRING IS EVER CHANGED)	• HIGH COST • MULTIPLE COCKPITS REQUIRE LARGER STORAGE FACILITIES FOR THE COCKPITS AND SOME SORT OF OVERHEAD CRANE DEVICE FOR COCKPIT INSTALLATION • SPARING REQUIREMENTS EXAGGERATED
INTERCHANGEABLE INDIVIDUAL COCKPIT MODULES (WITH EMBEDDED PROCESSORS)	• COCKPIT FIDELITY AND REALISM PRESERVED • MAJOR SECTIONS OF THE COCKPIT COULD BE RECONFIGURED IN A VERY RAPID FASHION BY A SINGLE TECHNICIAN • COMMON CONNECTIONS FOR SIGNAL, POWER AND COOLING PROVIDES FOR EFFICIENT STANDARDIZATION, REGARDLESS OF THE SPECIFIC AIRCRAFT CONFIGURATION • DISTRIBUTION OF LOCAL PROCESSING OR "INTELLIGENCE" IN MODULES ALLOW THESE MODULES TO BE EASILY CONNECTED AT THE DIGITAL LEVEL	• AN INTERNAL ADJUSTABLE SUPPORT STRUCTURE FOR ALL POTENTIAL COCKPIT CONTROLS AND DISPLAYS (FOR ALL AIRCRAFT CONFIGURATIONS) MUST BE CREATED • EMBEDDING PROCESSORS WITHIN EACH MODULE MAY HAVE PACKAGING CONSTRAINTS • ALL UNIQUE MODULES MUST BE SPARED

Table 1. Alternatives Summary

With the utilization of the interchangeable individual cockpit modules approach, utilization of operationally faithful hardware, while adhering to proper cockpit geometries, could be attained. Most of the disadvantages indicated above were strictly design issues which were solved during the conceptualization of the LCRC. The approach would also provide the capability of reconfiguration to a tandem seat configuration, as well as to rotorcraft. As will be described in the following section on design characteristics, utilization of embedded processors and graphics generators, with standardized interfaces, provided the needed modularity to provide functionality to the design.

Design Characteristics

The physical representation of the LCRC is shown in Figure 1. As shown, the LCRC hardware consists of a series of modules all of which attach to the Base Module. Specifically, the following modules comprise the cockpit:

- Base Module
- Side Console Modules
- Main Instrument Panel Module
- Subpanel Modules
- Center Stick Module
- Seat Module
- Video Generation Module
- Aft Equipment Module

The center stick is distinctly called out as a module since side-arm controllers are considered as part of a side console module (in the same manner that a throttle quadrant is considered part of a side console module). This is due to the rationale that a side-arm controller or a throttle quadrant will not be removed from the side console as a separate module.

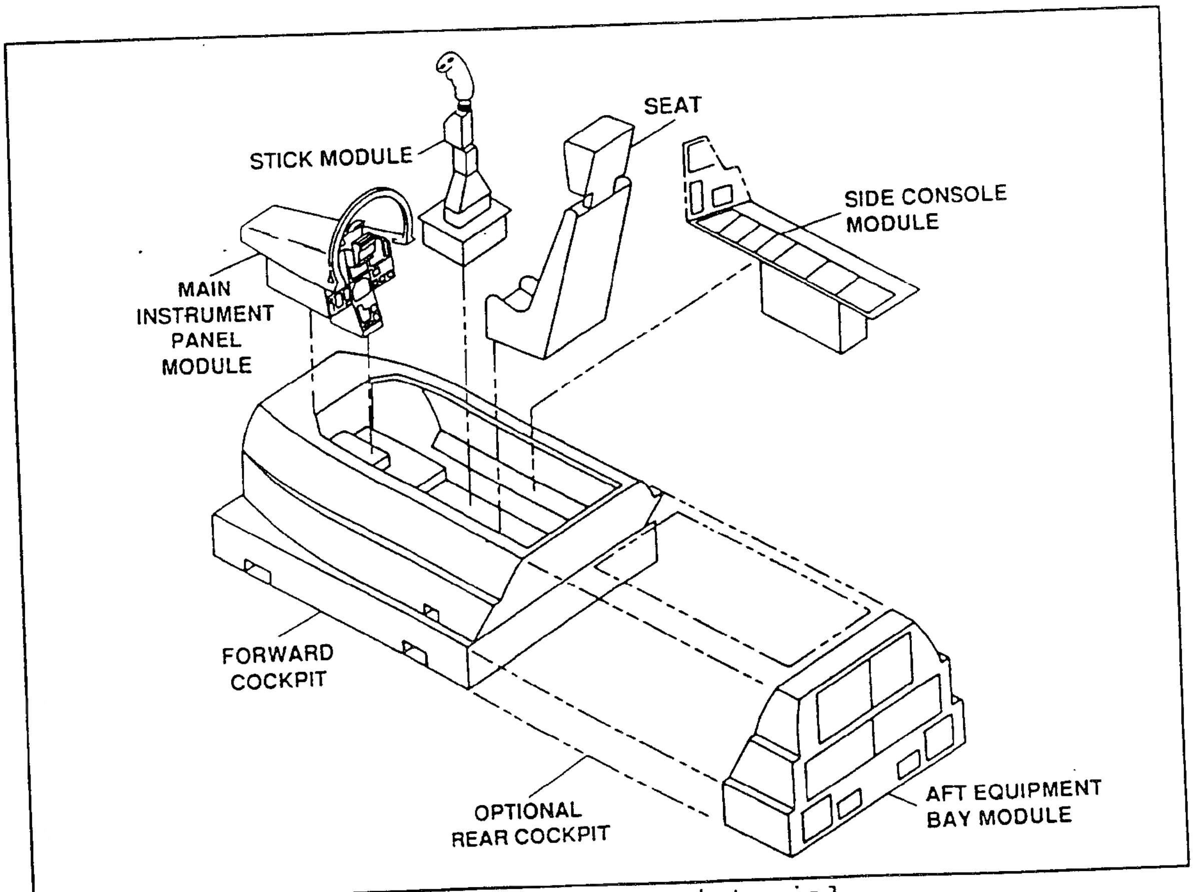


Figure 1. LCRC Pictorial

The displays are considered removable components, which integrate with the Main Instrument Panel Module and the Video Generation Module. The various electronic displays, such as the Head-Up Display, Head-Down Displays and the Electronic Warfare Displays are NOT shown in the LCRC Pictorial Drawing.

The LCRC hardware design is truly modular in three different ways. It is first, as described above, comprised of individual modules which are aircraft type specific. Thus, the true reconfigurability is contained at this level. Second, one LCRC can be directly connected to another, so that simulation of two seat tactical aircraft can be easily accomplished. In this manner, the forward LCRC Base Module merely acts as a "pass through" structure for power, grounding, signal and cooling networks. Third, the entire LCRC is just one modular component of the Tactical Team Trainer System. As such, the LCRC is designed to interface with other major subsystems such as, but not limited to, outside visual graphics generators, outside visual display systems, instructor operator stations, audio tone generators, and simulation host computers. To this end, *SYMVIONICS* has realized the necessity of incorporating systems engineering early in the design of such a complex device as the Tactical Team Trainer System, and has defined the LCRC accordingly.

The LCRC was designed to use embedded PC-based computers and peripherals whenever possible. The price, performance, variety and availability of peripherals for PC-based computers have been improving tremendously over time and will continue to do so in the future. Basing the design of the Cockpit on the PC provided the capability to keep the cost to the absolute minimum. The number of Pcs required will probably be able to be reduced as time progresses. Additionally, the use of a common structural base provided for an easy and effective method of using intelligent building blocks to create a desired cockpit configuration in a short period of time.

In the design of the LCRC, low-cost solutions were desired and expected. However, these low-cost alternatives would not be deemed acceptable unless a "full-fidelity" capability was still maintained. The primary use for the cockpit was to be for training tactics and weapon deployment, as well as team training (i.e., internetted operations). Missions to be examined include both Air-to-Air and Air-to-Ground. The designed LCRC was also to address shipboard use. Therefore, space and external hook-ups were to be minimized. That is, logistics concerns were to be analyzed, such that the resulting design would be easily and fully supported with minimal resources.

Based on specified top-level requirements and internally-derived detailed requirements, a systematic design activity matured a viable architecture for the LCRC. This design would satisfy all known requirements and could be used as an integral part of traditional training systems (such as tactics trainers, operational flight trainers and other part-task trainers) or even more current

[tra]ining thrusts, such as mission training or mission rehearsal. [To]p-level design features (or objectives) of the LCRC are shown in Figure 2.

- BASE DESIGNED TO ACCOMMODATE DIFFERENT VISUAL DISPLAY SYSTEMS
- ACCOMMODATE REAR-SEATER UPGRADE (DUAL LCRC)
- QUICK RECONFIGURATION TIME (SMALL NUMBER OF UNIQUE MODULES)
- PC'S PROVIDE ALL COMPUTATIONAL POWER
- LOW COST (NON-QUAL MATERIALS, FUNCTIONAL EQUIVALENTS)
- TRANSPORTABILITY (TOW HOLDS, EYEBOLTS, COUNTERWEIGHTED, CAN MOVE WHOLE COCKPIT/ALL MODULES IF DESIRED)
- LEVELING (LEVELING FEET)
- RECONFIGURATION IS A ONE OR TWO MAN EFFORT - LITTLE TRAINING REQUIRED
- INTERNAL SYSTEM DIAGNOSTICS AND CHECKOUT "TUTORS"
- EXTERNAL MOUNTING (STURDY EXTERNAL BASE BEAMS, BASE CAN BE USED TO MOUNT EVERYTHING, SUCH AS VISUALS)
- EXTERNAL ALIGNMENT (BASE CONTAINS KNOWN REFERENCE POINT FOR VISUAL SYSTEM UTILIZING MOUNTING GUIDE PINS)
- STANDARD EXTERNAL SUPPORT (ONE SET OF DISCONNECT PANELS, BASIC POWER/GROUND, ETHERNET, SENSOR SIMULATOR VIDEO, NO COOLING AIR)
- HARDMOUNTS ON BASE TO ATTACH ENTIRE TACTICAL TEAM TRAINER SYSTEM TO SHIP FLOOR

Figure 2. LCRC Design Features

Figure 3 depicts a top-level functional block diagram or architecture of the *SYMVIONICS* LCRC. This architecture is characterized by multiple graphics processors which are dedicated to driving the various cockpit displays. Additionally, Pcs are embedded within various cockpit panels to provided localized signal interface and data conversion, such that the module provides intelligence back to the main Simulator Host Computational System at a digital level. Additionally, there is enough processing power within the cockpit to perform subsystem modelling.

The *SYMVIONICS* LCRC hardware design innovations focused in three specific areas: "Modules" and the definition of modularity, Pcs as the interface computer and a Base Module which provides both facility functions and commonality among all cockpit configurations. These areas of innovation influenced the hardware design for all components as discussed below.

Modules

By dividing up the entire cockpit into removable, replaceable "smart" units, design factors were then imposed on each module. Some of these include: commonality of parts (connectors, wire, fasteners, valves), sizing of module (to accommodate PC interface computer), mounting type and location (for commonality among aircraft types) and interface type and location (to simplify design of the Base Module). While these factors led to more constraints being imposed on each module's detail design, they are in fact the very considerations which give the modular designed LCRC its inherent lower complexity, higher reliability and lower

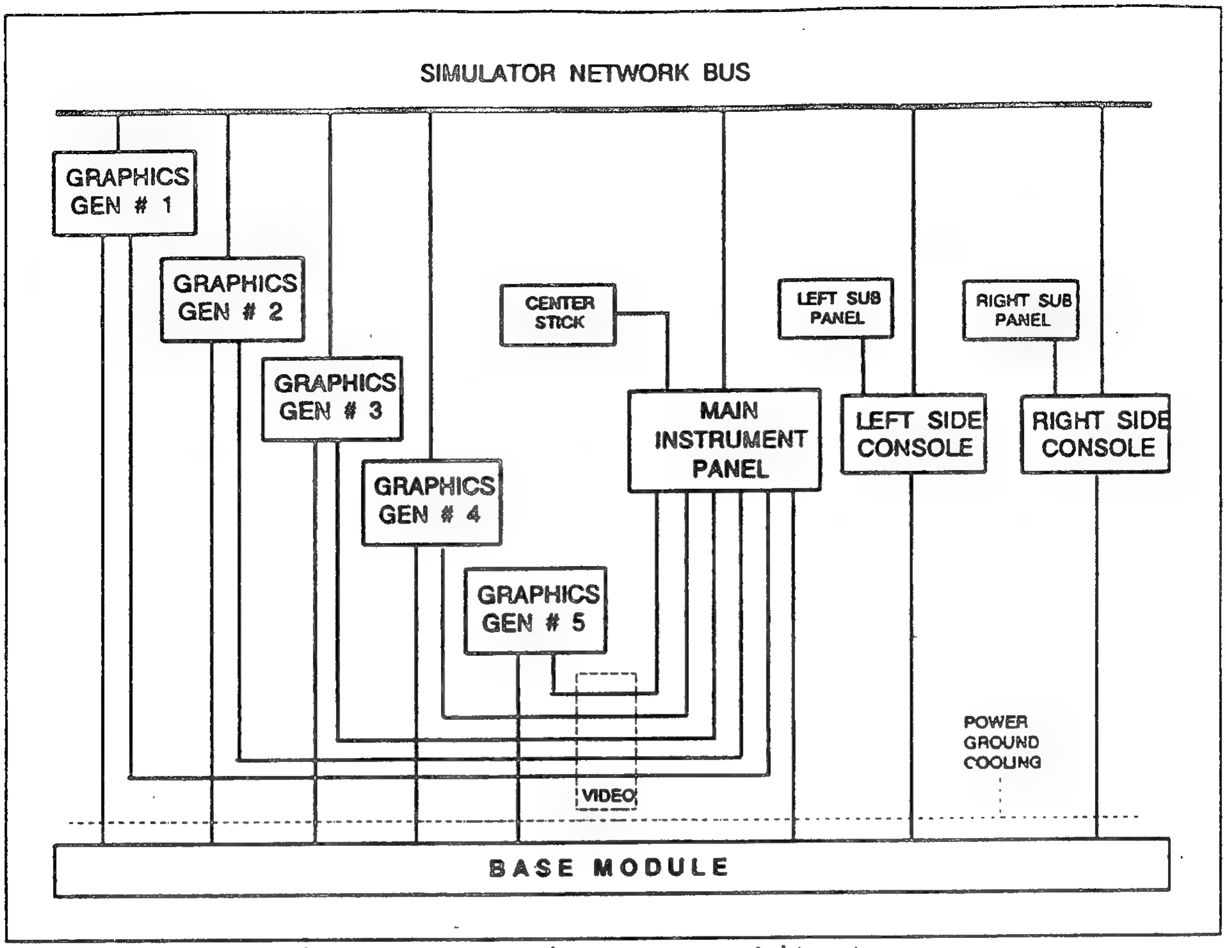


Figure 3. Basic LCRC Architecture

maintainability than conventional simulator cockpits. In addition (and very important), the modular design allows for quicker reconfiguration between aircraft types. A basic module configuration is shown in Figure 4.

PCs as the Interface Computer

Several types of computer systems were investigated for use in the LCRC. For example, many single board computers, peripherals and mounting racks are available for VME and Multibus architectures. These systems are relatively expensive and bulky. They lend themselves more to designs that feature a centralized computer system rather than our federated design concept. PC based computers are less expensive than VME or Multibus systems and peripherals are available to support all of the LCRC requirements.

A direct flow-down hardware design requirement for the use of embedded processors within the LCRC is to dimensionally house at least one card cage, PC motherboard and Input/Output (I/O) card in every module which processes I/O. This then produces derived requirements for each module to have appropriate power, grounding, signal and cooling be distributed to it.

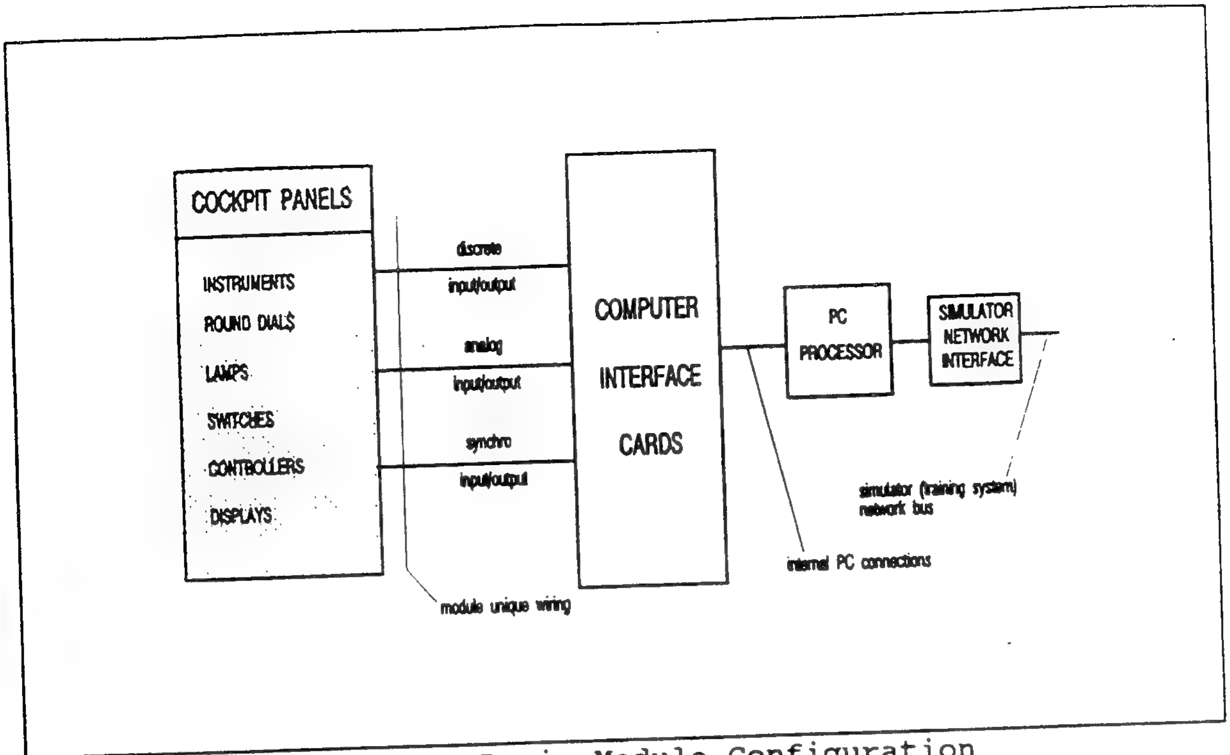


Figure 4. Basic Module Configuration

Base Module

Some of the requirements for a base structure for the LCRC were explicit at the outset of the program. There always had to be a foundation structure on which all else would be built upon. There also had to be some module in the LCRC which would be common to all aircraft types, those known now and those in the foreseeable future. However, as requirements analysis progressed, the viability of another innovative design concept clearly emerged - that of the Base Module. The innovation of the design came about in fulfilling derived requirements of the program. These requirements for the Base Module were basically twofold.

First, the Base Module is required to provide all other modules with the appropriate mechanical mounting, power, grounding, signals and cooling which they need. As the modules became better defined and they became more federated (or distributed within the LCRC), the functions which the Base Module had to support began to grow. Such requirements as transportability, power conversion, autonomous cooling, and operational logistics (storage, reconfigure time, checkout time) all were fulfilled by the Base Module.

Second, it is required to provide for all interfaces external to the LCRC itself, such as mechanical alignment, facility supplied power and host computer data. As many of these external technical interfaces were not completely defined, the result was to design a Base Module which made the LCRC very versatile. For example, it needed to accommodate different types of out-the-window display

systems and trainer style fore/aft seating. The *SYMVIONICS* des..n provides an effective and convenient mechanism for converti.. single seat aircraft into a dual seat (tandem) airc... configuration.

Reconfigurable Cockpit Operations

Operations with the LCRC are designed to allow a sing.. technician to perform a checkout of the entire cockpit operation i. a relatively short period of time. This can be accomplished based on the modularity of the design, as well as by exploiting th. processing capability and internal graphics generation capabil..y inherent in the LCRC. The hardware design supports this concep. through the use of self-aligning modules, quick disconnect fasteners and minimal numbers of modules and connections. The software design also meets this requirement through the use of diagnostic routines, which are limited in speed only by the hum.. operator running through them. It is estimated to take onl. . hours to <u>fully assemble</u> and initially checkout an LCRC in any single seat aircraft configuration. More importantly, *SYMVIONIC..* estimates that it will only take 1 hour to <u>reconfigure the L...</u> <u>between aircraft types</u>, once initially assembled.

The *SYMVIONICS* LCRC has also been designed to provide compl... interoperability and compatibility with other simulator syst.. which would normally be provided within a complete training syst.. These subsystems include the following: Simulation H.. Computational System, Visual Display System, Sensor Simulators, Motion System, Sound System/Intercom and Instructor Operator Station.

Summary

The reconfigurable cockpit technology described herein affords the potential user a viable fidelity and cost driven design. The application and use of commercially available products helps reduc.. manufacturing and maintenance costs and assures increase system reliability. The design strategy easily allows for application t. other aircraft platforms. The design of the cockpit, even without the reconfigurability, allows for a cost effective cockpit solution to many low cost flight simulation requirements. The reconfigurability and deployable features of the design coul. afford the user a high fidelity simulation solutions at locatio.. almost anywhere desired.

SYMVIONICS has developed the complete architecture and t. level design for a modularized, reconfigurable cockpit . deployable aircrew tactics team training. The LCRC concept cent. around the judicious use of embedded PC-based processors an. graphics systems. The power of these systems, which commercially available is phenomenal. The activity described . based on a study involving the systems engineering evaluation .

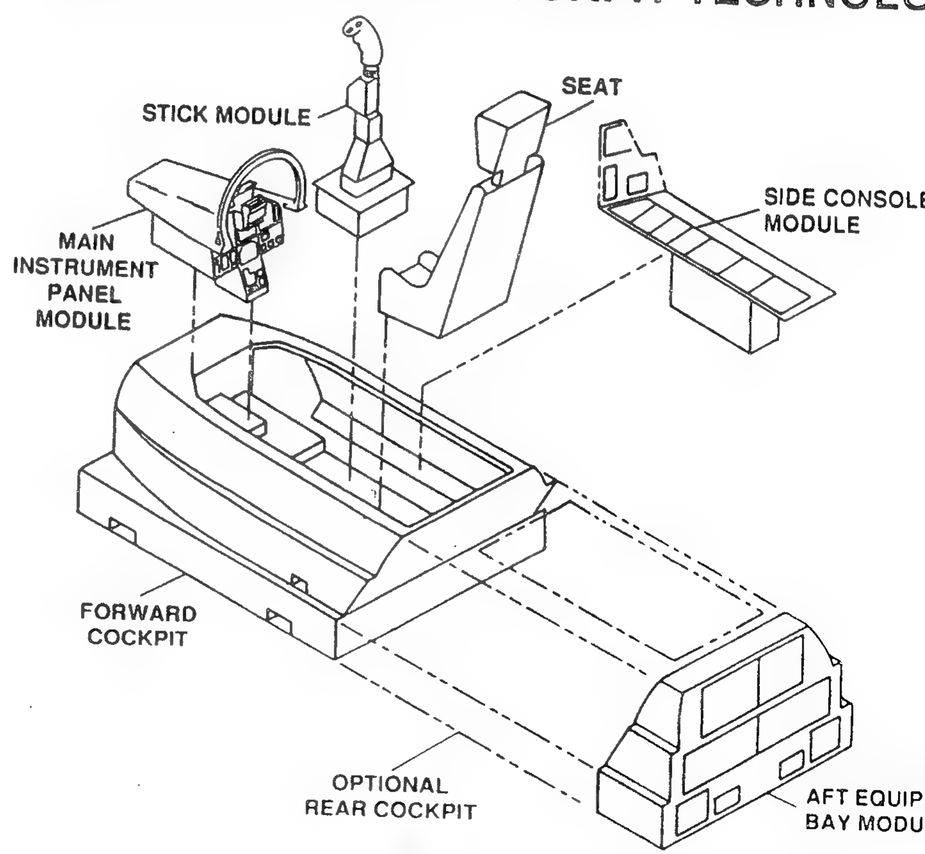
the requirements and functional aspects of the reconfigurable cockpit. *SYMVIONICS* is actively pursuing development options that would initially lead to a hardware prototype with development of the software in Ada.

About the Authors

Mr. Richard A. Weeks holds a M.S. in Engineering and a M.S. & B.S. in Aerospace Engineering. He was the Principal Investigator for the Low Cost Reconfigurable Cockpit for Tactics/Team Training effort at *SYMVIONICS*. Mr. Weeks specializes in the development of full mission simulation systems for both training applications and new weapon system developments. He was thoroughly involved in the development of full mission simulations of weapon systems such as the F/A-18, B-2, F-22 and C-17 aircraft. He has also performed numerous trade studies regarding the stimulation of actual avionics processors and Operational Flight Programs in training devices for enhanced fidelity and concurrency.

Mr. Thomas C. Kopke holds a B.S. in Physics and is presently employed as a Physicist at the Naval Training Systems Center (since 1983). He is also an adjunct professor of Physics at Jacksonville University. He is currently responsible for simulation systems research in the areas of helmet mounted displays and low cost flight simulation systems. Past areas of research include embedded training and head tracked display flight simulation systems. Specific efforts have been accomplished in in-flight embedded training, low-cost NVG simulation systems, CGI development, eye tracking, head tracking, deployable aircraft trainers, Helmet Mounted Displays, projection screen technology and stereo vision.

RECONFIGURABLE COCKPIT TECHNOLOGY



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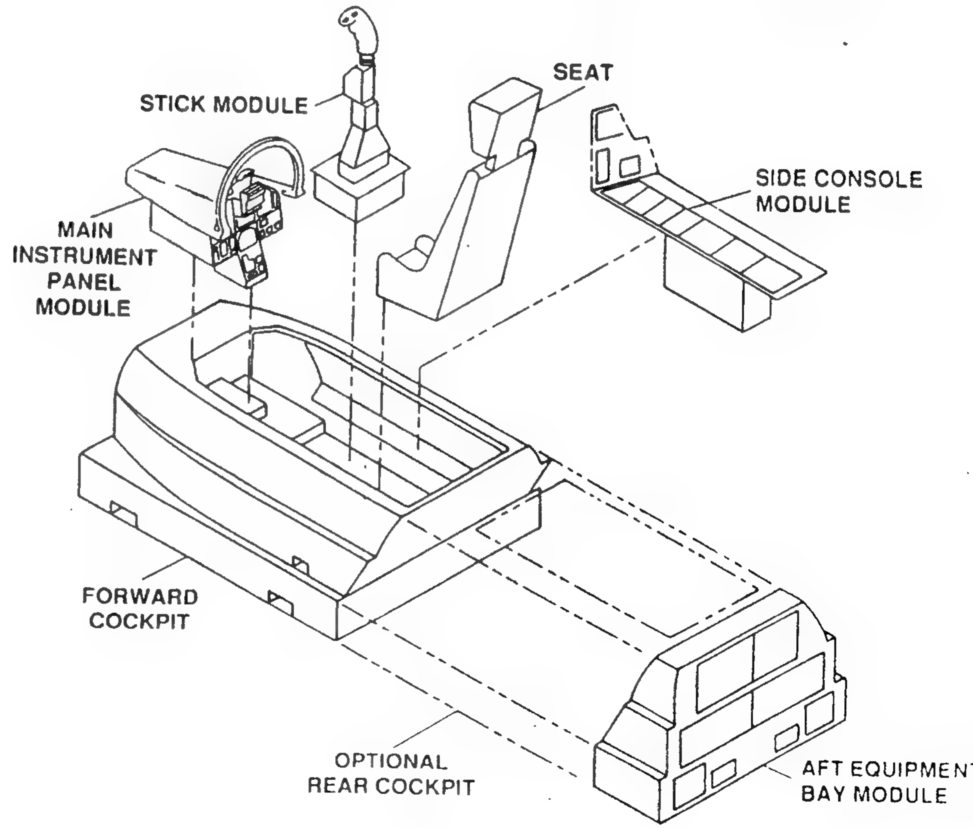
RECONFIGURABLE COCKPIT TECHNOLOGY



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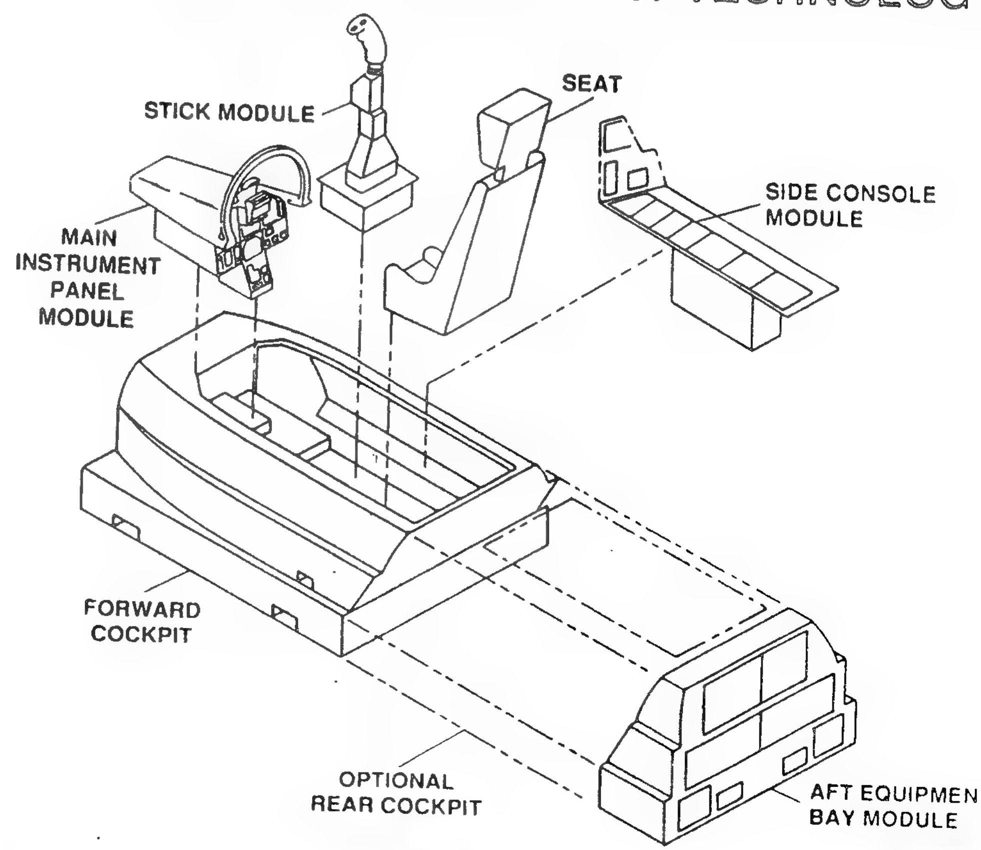

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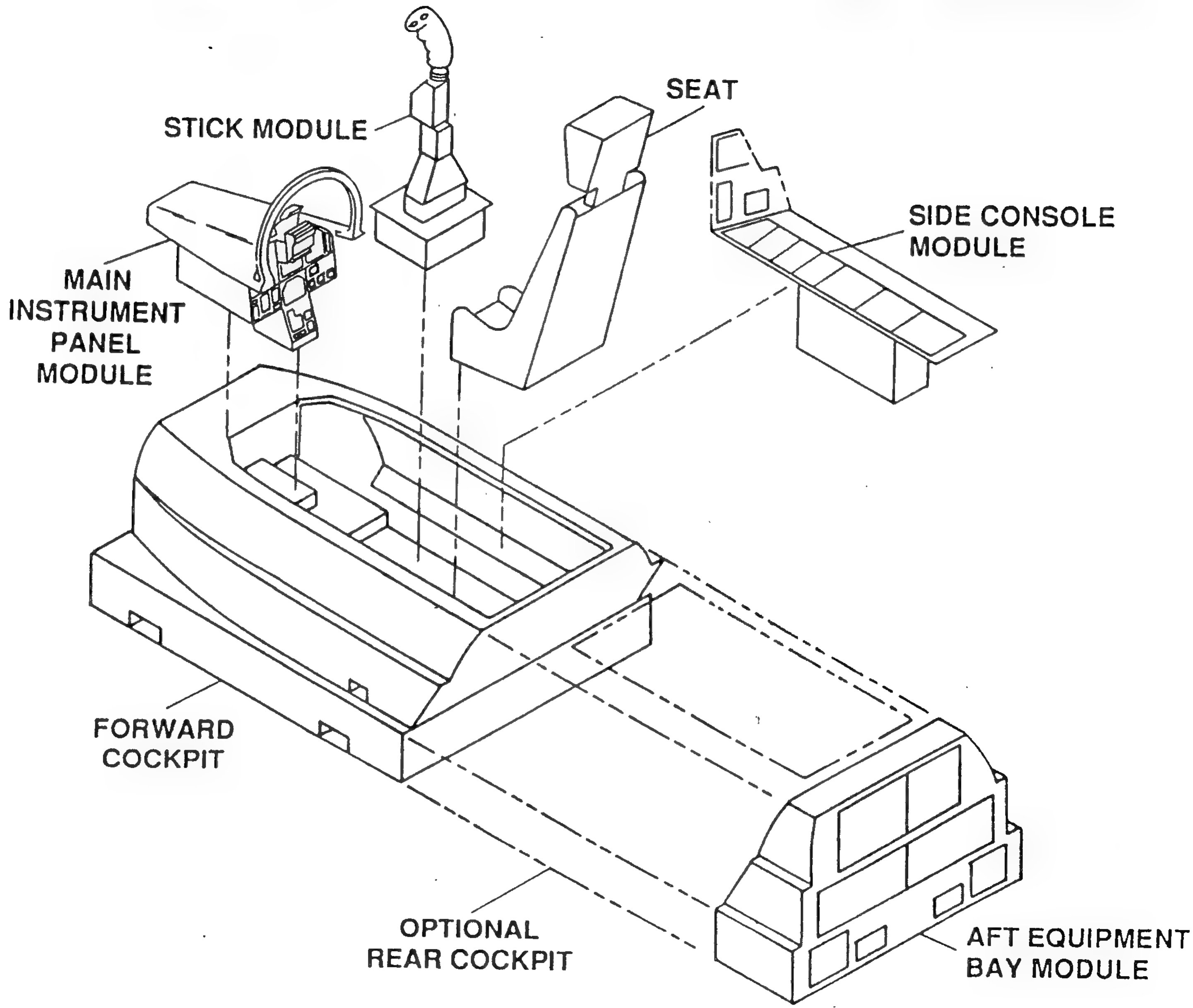

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Interactive Graphical Models in Training: Authoring Tool Requirements

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Douglas M. Towne

University of Southern California

Computer based training (CBT) has not proven itself a universal panacea for technical training. Worst-case examples of CBT provide inflexible, non-portable, low resolution, expensive, demotivating experiences. Best-case examples provide highly motivating, interactive, simulation-based, adaptive instruction — but such examples are ordinarily very expensive to develop using traditional technologies.

Our laboratory has been engaged for more than a decade in the development of a series of instructional environments with integrated authoring tools based on the principal of *model-centered* computer based training (CBT). Model-centered CBT systems developed or designed at our laboratory include the generalized maintenance training system (GMTS), the equipment simulation authoring system (ESAS), the intelligent maintenance training system (IMTS), and the rapid intelligent tutor prototyping development system (RAPIDS). These experiences, together with progress in human interface design, have led to the formulation of a set of requirements for effective and economical model-centered CBT authoring tools.

Model-Centered Computer-Based Training

In model-centered CBT, students interact with graphical representations of complex devices or systems. When a student touches a pictured switch or other control, the pictured device changes to reflect the effects of the manipulation. The propagated visual effects are determined by specifications about how the real device or system works. These specifications may be expressed at a deep level, reflecting the actual processes involved in the device behaviors, or at superficial levels that produce the visual effects without representing the internal mechanisms.

The representation of a device can consist of a single screen-sized view, called a *scene*, or many scenes. The representation used in model-centered CBT could be an interactive schematic that exhibits internal workings, such as a helicopter bladefolding system (Figure 1) or an operational front panel of a device such as a satellite communications system (Figure 2) or a VCR (Figure 3).

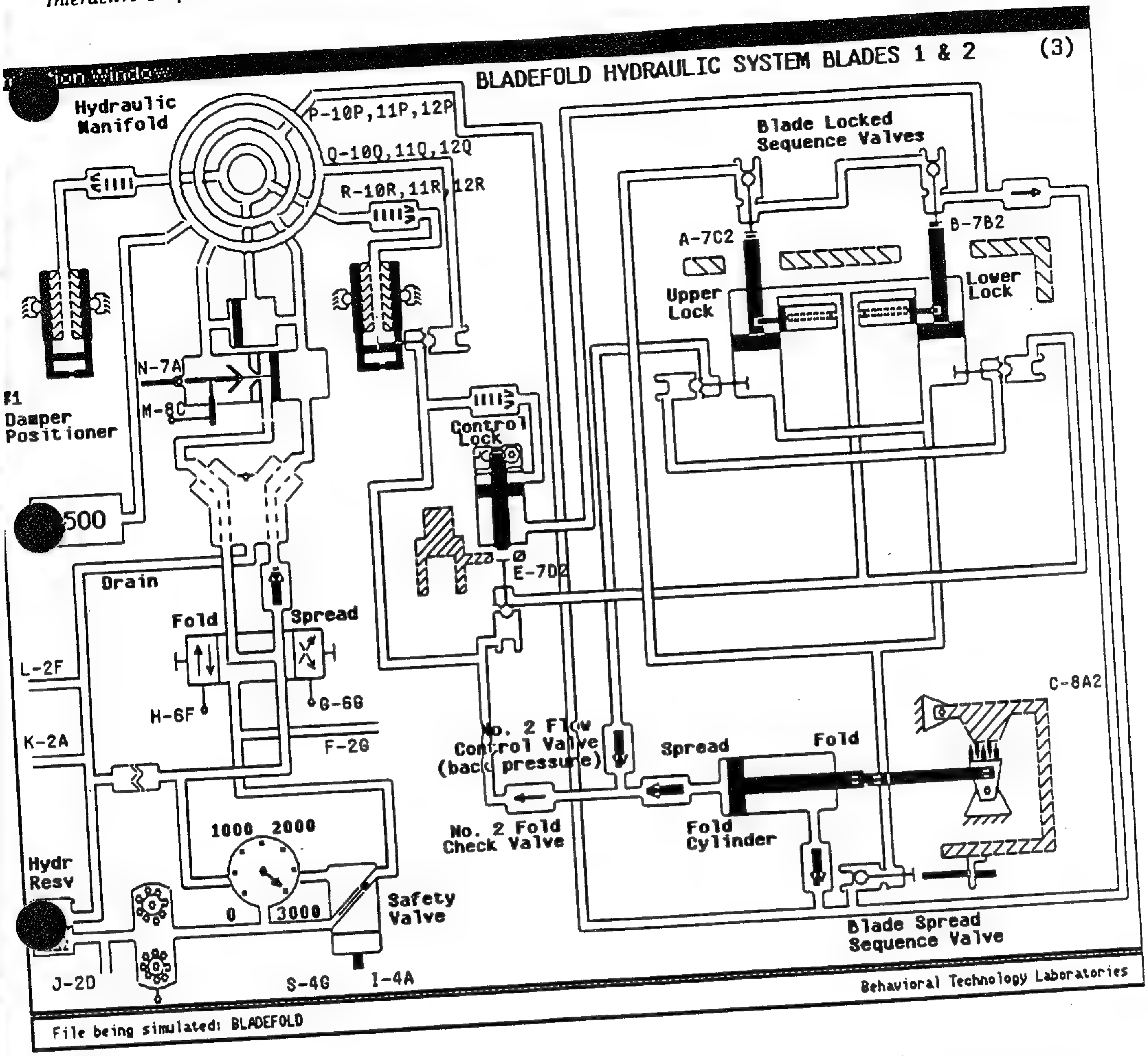

Figure 1. One of Fourteen Scenes in a Helicopter Bladefolding System Model

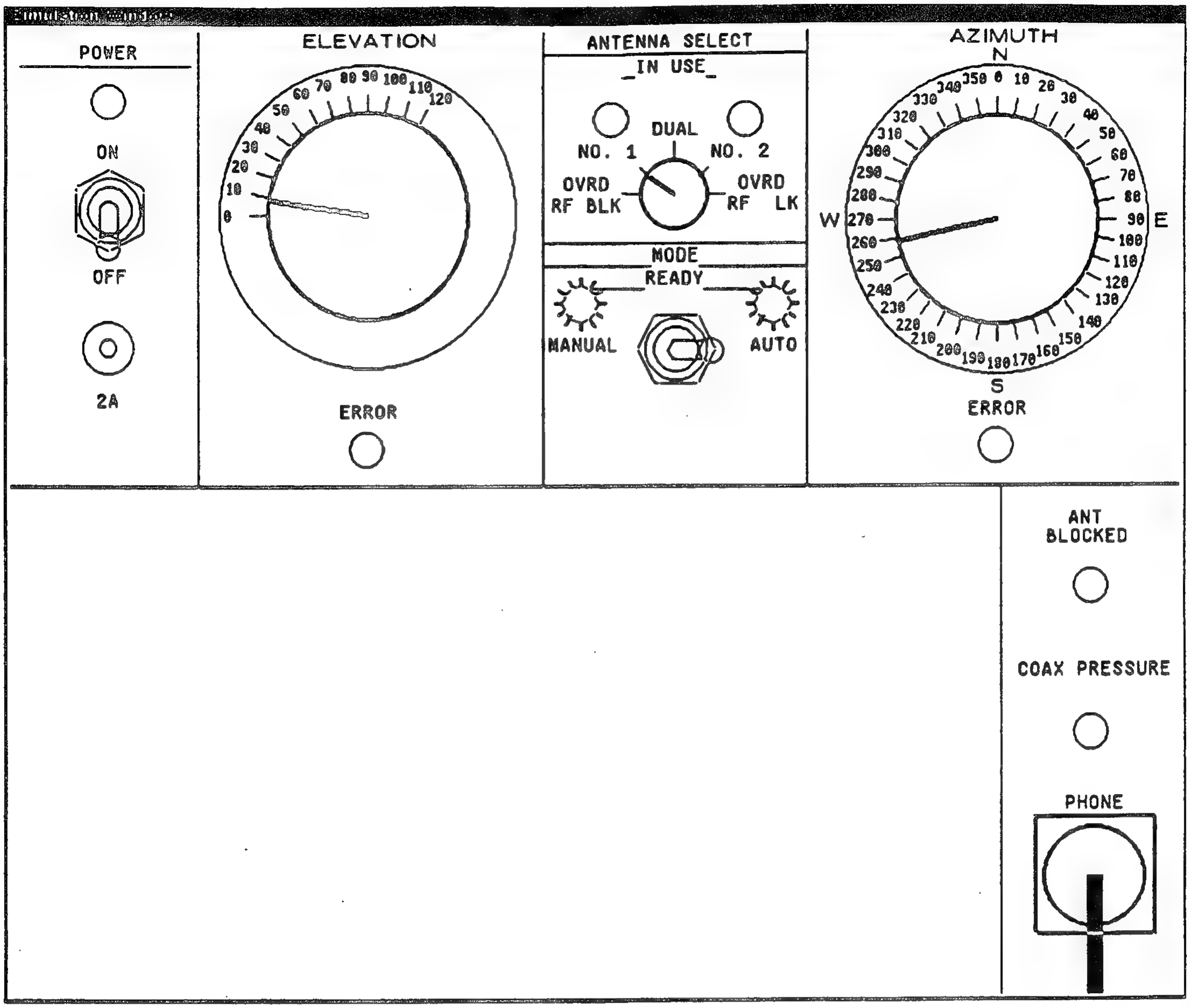

Figure 2. One Scene From a Satellite Communications System Model

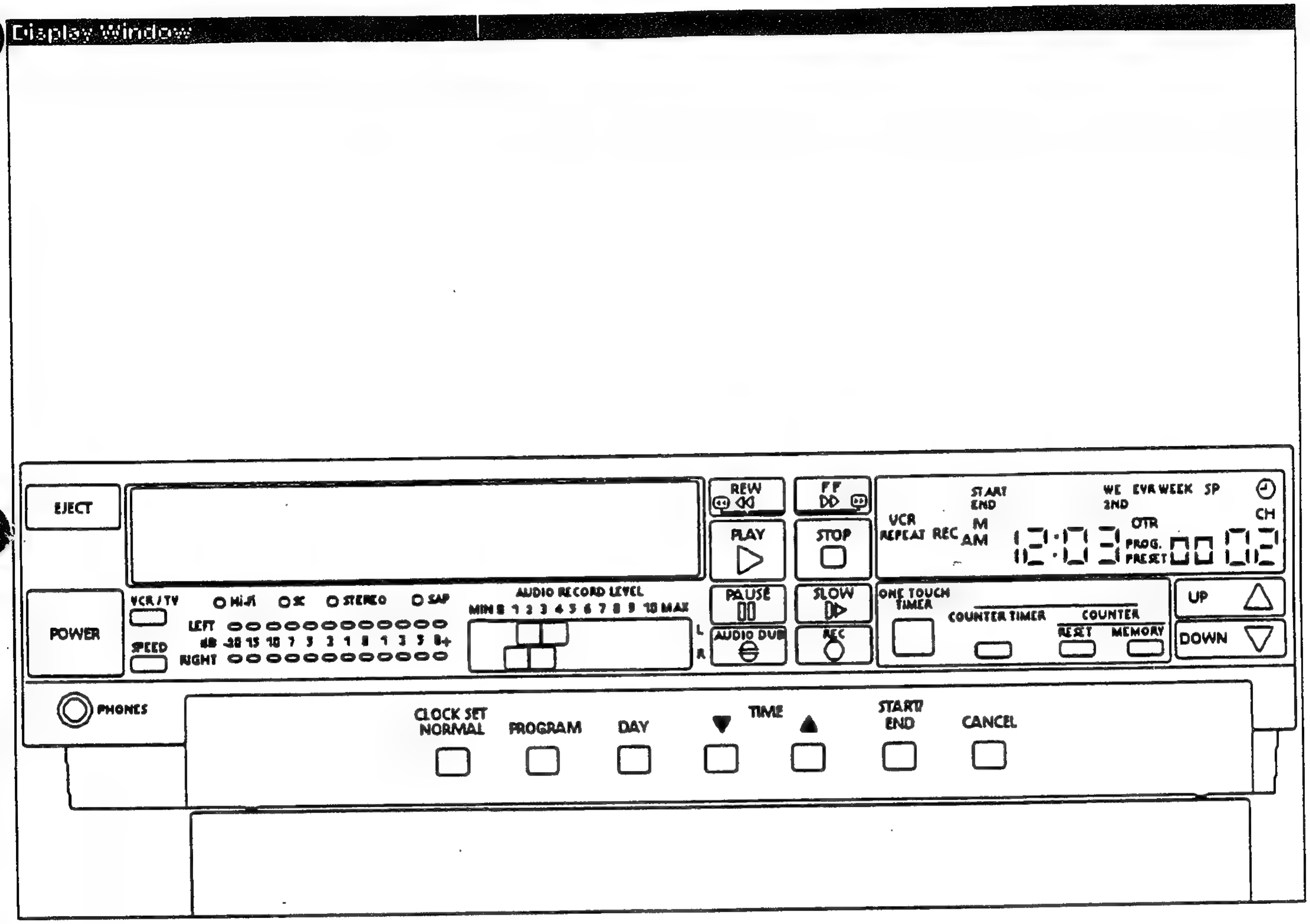

Figure 3. A VCR Front Panel Training Simulation

Direct Manipulation. In model-centered CBT, students manipulate elements of the graphical model in a manner that is cognitively congruent to the way that a real device is manipulated, and they see responses of the device that are either realistic or instructionally meaningful. When the student clicks the mouse pointer on the right contact of the switch in Figure 4A, the switch changes its appearance to that shown in Figure 4B. The ability to change the appearance or location of an object by clicking on it or dragging it is called *direct manipulation.*

Automatic Propagation. When the switch position is changed, other effects propagate through the graphical model. The valve changes state from straight to crossed, the piston starts to move, the contact switch is pushed down, and the light turns on. This sequence of effects results from the direct manipulation of the switch by the student and the behaviorally defined objects that are connected to the switch directly or indirectly.

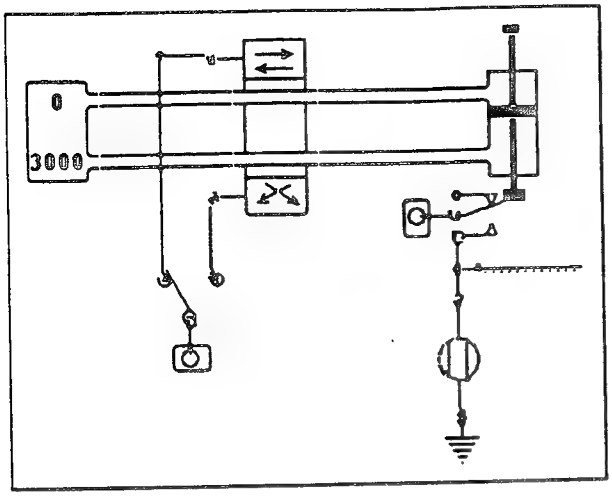

Figure 4A. Before Clicking the Switch

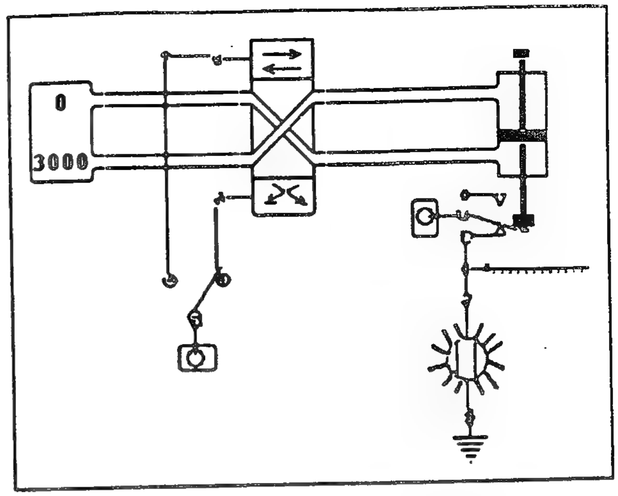

Figure 4B. After Clicking the Switch

Training in a model-based context. Without any further authoring effort such interactive models allow the student to practice and explore. Moreover, instructors can employ the model in a classroom to demonstrate procedures or complex system behaviors.

Authors typically will produce additional instructional scenarios, however, by manipulating the model and elaborating the rationale for their actions and the processes involved in the system responses. These retained operational and instructional actions by the author can then be delivered to the student in a manner that is sensitive to the individual's ability. A wide range of instructional methodologies can be implemented. Students can be required to operate the model in a highly structured manner, reproducing previously demonstrated sequences exactly. Alternatively, instruction can focus on deep causal relationships that will enable the student to construct action sequences that will attain complex system goals, or to isolate the source of simulated failures. Additionally, traditional CBT interactions are supported, such as choosing an answer to a question from a menu of possible answers, typing an answer to a question, and so on.

Figure 5 shows a portion of the screen during a training session based on an interactive schematic model of a jet engine starting system. Here a student is being led through a sequence of steps. The training delivery system automatically provides informational feedback on incorrect actions and can even carry out actions on the model to demonstrate them to the student who fails after repeated prompting.

These kinds of student interactions, and the underlying cognitive processes involved in evoking them, differ markedly from the simple responses permitted in conventional CBT not employing an active model. Thus, in our experience, model-centered CBT offers a significantly enhanced training experience, with much greater potential for transfer of training to real work environments.

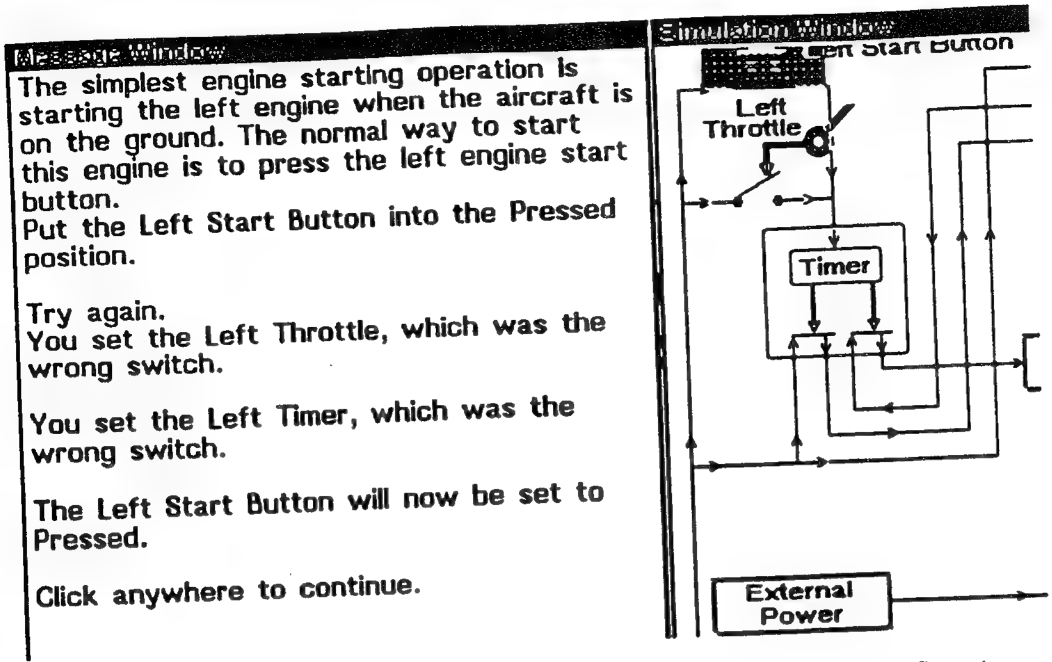

Figure 5. A Portion of the Student Interface During a Model-Centered Training Exercise

The capabilities required to author model-centered CBT include the development of visual representations of device elements, the authoring of model behavior, and the creation of instruction based on the model. Traditional technologies for developing the best kinds of CBT require the application of computer programming skills. Applying these skills to create interactive simulation training is laborious and it requires the services of professional programmers. Rarely are such programming specialists also experts in training specialties or in the particular technical domain being instructed. Only when powerful model-construction tools are provided in an integrated instructional-development environment can the cost and required skill levels for authoring be made manageable.

In the remainder of this paper, we present a set of requirements for model-centered CBT development. We divide these requirements into these four task areas: course planning, model presentation authoring, model behavior authoring, and instructional development.

Requirements for Course Planning

Certain tasks must be accomplished to create model-centered training, whether the course is developed using model-centered authoring tools or more conventional programming methods. In RAPIDS, authors plan a course by creating a hierarchical structure in which the terminal nodes represent instructional units (actual instructional presentations) and intermediate nodes represent instructional goals (Figure 6). Authors can specify conditions under which a branch of the course tree is presented to a student.

The purpose of course planning is to control the order of presentation of instructional units and to allocate time to the various topics, if desired. The most simple course plans are not adaptive; all students will receive the same sequence of instruction. More elaborate course plans may provide many possible sequences of instruction, depending on student performance and/or student preferences.

Developers of CBT authoring systems are faced with a natural tension between requirements that promote productivity for inexperienced course developers and requirements for flexibility and elaborate run-time control that are demanded by sophisticated course developers. Our experiences lead us to believe that both types of requirements can be met in a system that provides a convenient standard approach that will satisfy the needs of most developers together with special features that can be used by experienced authors to achieve more elaborate course control effects.

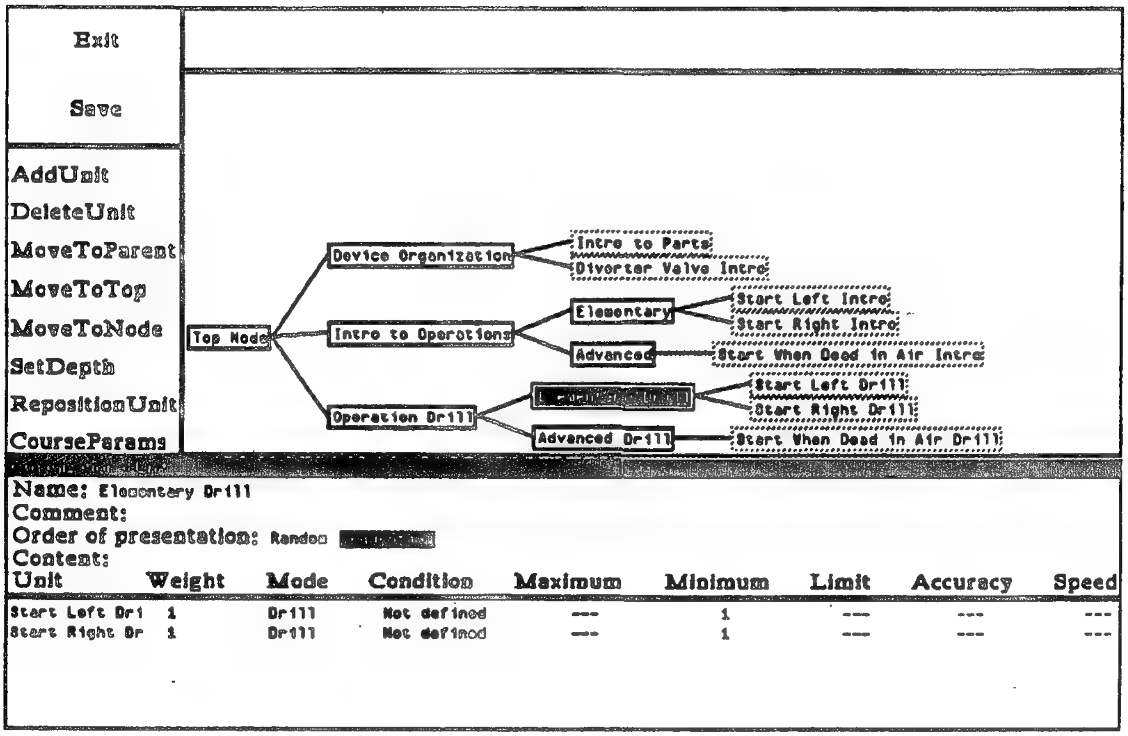

Figure 6. A Course Plan for RAPIDS

The requirements we note for course planning are these:

- R1. *A simple technique for creating a default plan*
  If a model-centered authoring tool is to have utility for the rapid prototyping of interactive graphical courses, it must make it easy to build a course that simply consists of a sequence of instructional units. Many authors who are not experts in theories of pedagogy simply want to have their students carry out a sequence of exercises.

- R2. *A non-programming approach that provides some control over which instructional units are presented*
  The next step up in sophistication in instructional planning is one that makes it possible to specify that a module of instruction should not be presented if the student meets certain criteria. In RAPIDS, authors can go through a sequence of menu commands to create simple rules that specify that modules be skipped if a student has met certain performance criteria on other parts of the course.

- R3. *Graphical display and editing of course structures*
  Non-programmers find it difficult to envision the layout of a course when that layout is expressed through a set of conditional (if…then…else…) statements. Some graphical representation of the course structure is desirable. Authors should be able to select course elements in this representation during the process of authoring and editing the course plan.

- R4. *Planning should be supported in advance of instructional authoring*
  It should be possible to create instructional plans without having yet developed the instructional modules that the plan will invoke in the student run-time environment.

- R5. *Authors should be able to refer to instructional units from a developing course plan*
  In RAPIDS, authors can click on a terminal node of a plan tree (terminal nodes represent actual instructional units — see Figure 7, above) in order to bring up a menu of available instructional units that could represent the node. Making a selection from this menu binds the actual element of authored instruction to that part of the course plan.

- R6. *Features for implementing opportunistic instruction*
  In addition to having an encompassing plan of instruction, many authors would also like to be able to implement opportunistic instruction in a CBT system. That is, whenever a certain condition occurs, a certain instructional unit should be presented. For example, when a high-voltage electrical safety violation occurs, the author may want a short unit on safety procedures to be presented. A course planning system should make it possible for authors to author conditional expressions that will control the presentation of these types of course elements.

Requirements for Producing Model Representations

Features in support of the presentation of a simulation model should permit productive development of graphical objects with a wide range of graphical complexity. It should be easy for developers to simply scan existing graphics and begin developing instruction based on the pictures. Alternatively, authors should be able to quickly copy and adapt graphical objects produced previously for other models.

Finally, authors must be able to quickly build new graphical objects in which the color, rotation, location, line thickness, and other appearance attributes of can depend on the values of variables in the simulation model. To draw a new object requires the use of a graphics editor, as shown below.

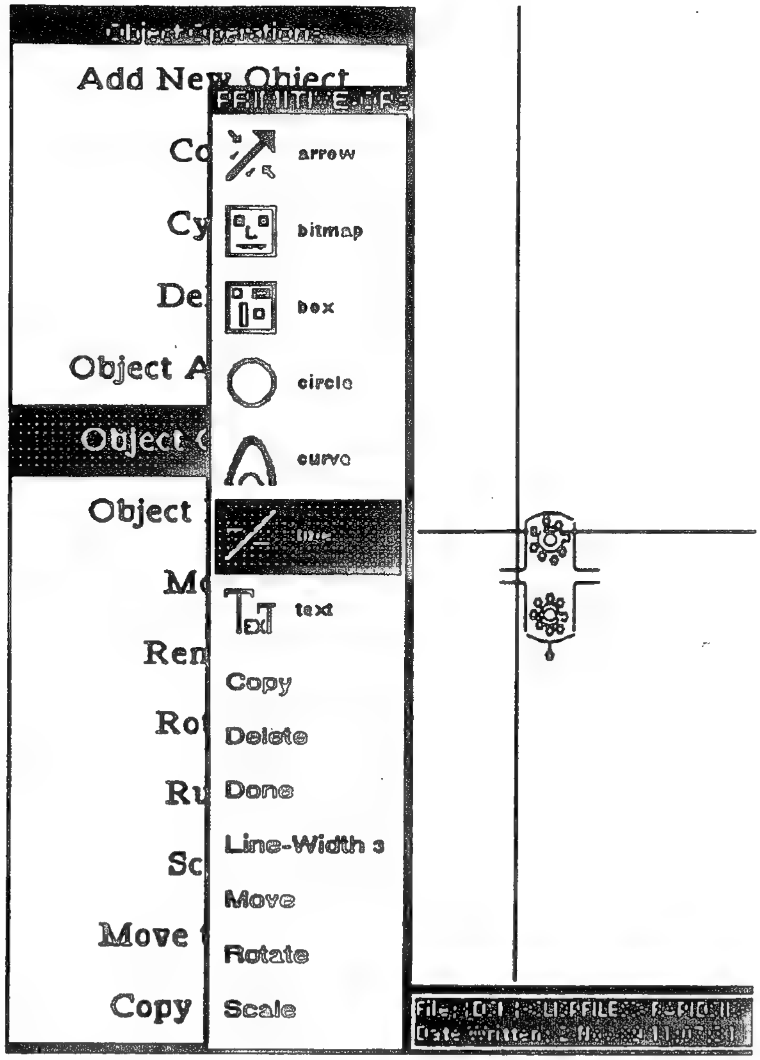

Figure 7. Drawing with a Palette of Drawing Tools

- R7. *Object permanence, manipulability, and editability*
  Graphical objects must retain their object character. That is, the composed scene should not be stored simply as a bitmap of pixels, but rather as a collection of objects composed of elements such as circles, lines, rectangles, and individual bitmaps. Authors must be able to copy, paste, and delete objects and collections of objects, as well as change the order in which objects are drawn (moving them from back to front, and so on), and change their intrinsic graphical attributes. Such attributes include the locations of the objects, the line thickness of those objects that are made up of line components, and their fill colors and line colors.

- R8. *The requirement of least astonishment*
  This requirement is a shorthand expression of a large number of human interface design rules. Graphical editors should behave in as un-astonishing a fashion as possible. This means both that they should, as far as possible, reflect the behavior of objects in the real world, and that they should adhere to interface standards with which users may already be familiar (Apple Computer, 1987; IBM, 1989).

- R9. *Graphical power*
  Two types of graphical power are required for successful model-centered CBT. First, the drawing tools provided to authors must provide a feature set that makes possible the composition of expressive and effective images. This means, for example, that advanced features for drawing and editing curved figures may be needed. Similarly, a more advanced approach to color choice and editing than a simple sixteen-color palette will be necessary for many training applications. Second, drawn objects must be rendered quickly. Many CBT models will deliver animation effects by rapidly erasing and redrawing objects in model scenes. There is a natural conflict between these two requirements for graphical power. Many CAD systems are based on drawing packages that permit extremely precise and expressive image authoring draw much too slowly for CBT use. A successful authoring system for model-centered CBT will balance the requirements for fine graphical control and for speed to produce appropriate performance.

- R10. *Importation of images*
  Authors will often be able to prototype a CBT trainer or even build a complete model using images that have been scanned from existing technical or training manuals or using images digitized from video. Ideally, a model-centered CBT authoring system will not only support the importation of scanned and digitized images, but will be able to paste graphics that have been created in other applications. This feature will make it possible to paste graphics that have been created using commercial graphic editors that support standards for graphic data export.

Requirements for Defining the Behavior of Component Objects

The behavior of objects must be defined so that the model will respond appropriately when model elements are manipulated. In RAPIDS, authors can write rules that determine how objects behave. In some systems, computer programmers write complete simulation programs, and then link aspects of the appearances of objects to the values of variables used in the simulation program.

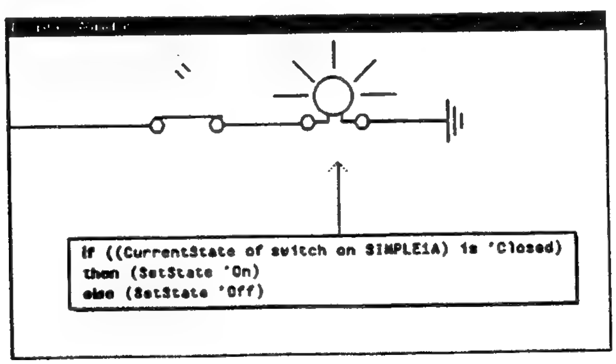

Figure 8. A Rule that Determines the Appearance of an Object

We have found that many non-programming individuals can learn to write rules that control the values of simulation variables called attributes. Some of these attributes determine the appearances of objects. If the simulation variables are associated with particular objects — that is, they are attributes of the graphical objects — then authors have a natural way of accessing the attributes and the rules that govern their values.

- R11. *Intrinsic (especially graphical) attributes*
  Many changes in the appearances of graphical objects can be expressed in terms of the attributes of some of the graphical elements of the model. For example, the value portrayed by a meter may be expressed in terms of the *rotation* of the meter's needle. The height of a bar on a bar chart can be expressed in terms of the *length* of the bar. Attributes like length and rotation are intrinsic attributes. Every graphical element has the *location* attribute. Line type elements have *length, line thickness*, and *line color*. Authors can control the appearances of graphical elements by writing rules that determine the values of these intrinsic graphical attributes. Whenever one of these attributes changes in value, the object is redrawn.

- R12. *Author-defined attributes*
  Authors must not be restricted to using intrinsic attributes in their simulations. When an economist creates a model for training, he or she may create a 'gross domestic product' attribute. When a hydraulics maintenance instructor develops a CBT application, he or she may define a new attribute called 'Port C2 input pressure' for a particular valve.

- R13. *Behavior authoring without programming the flow of control*
  While many non-programmers can write rules that determine the values of attributes, it is more difficult for most of them to create program control structures that determine the order in which such rules are evaluated. One of the tasks that a model-centered CBT simulation must carry out for the author is to determine behind the scenes how simulation effects should propagate among attributes that can affect each other.

- R14. *A natural expression syntax*
  The expression of value-determining rules should be as natural and as readable as possible. Iconic representations of logical and/or mathematical relationships seem to be less clear for most authors than using words like 'if' and 'then.'

- R15. *Rules for responding to student actions*
  The rule syntax must have natural ways of referring to student actions, such as clicking on an object.

- R16. *Modeling real-time processes*
  In addition to providing an expression syntax for assigning values to object attributes, a model-centered system for technical training should facilitate the authoring of time-dependent processes that change attribute values gradually, once they have been activated. It should also be possible to author rules that interrupt these processes.

- R17. *Scheduling events*
  Rules should be able to schedule events. This makes it possible to write a simulation that explodes a bomb at a fixed time after its fuse is lit. Rules must also be able to deschedule events. This makes it possible to simulate the fuse being extinguished.

- R18. *Aid in rule authoring*
  A rule authoring system should offer many types of support for model authors.

  Menu-based rule authoring. It should be possible for an author to select a rule or a portion of a rule and ask for a menu of options for editing that rule. The menu

should be context-sensitive, so that it offers only syntactically correct alternatives for the selected rule segment.

Authoring certain types of rules graphically. In RAPIDS, authors are able to create simple rules that assign the value of one attribute to another attribute simply by making a series of menu choices and mouse clicks on the two objects.

- R19. *Interactive model debugging features*
  Most complex models are likely to require some debugging during their development. Authors sometimes write rules that don't carry out the intended assignments, or they fail to write planned rules, so that no value is established for an attribute. A number of debugging features can significantly improve the utility of the model-au.horing environment. These include the following optional features:
  - Dialog views of object and attribute data
  - Graphs of attribute effect propagation
  - Pausing on rule evaluation
  - Pausing on attribute value changes
  - Stepping through rule evaluations
  - Correcting attribute value errors (e.g., 'no value provided') at run time

Requirements for Authoring Instruction

In RAPIDS, instructional units are authored primarily by directly operating the graphical model. For example, an author can create a required student identification task by choosing a 'Find Object' option from a menu of instructional item types, and then clicking on the object that the student is to find. A student prompt (e.g., 'Find the Left Start Button') is presented automatically as a result of these simple authoring actions, as are all ensuing interactions with the student including detection and correction of student errors. In a similar manner, procedures are demonstrated and explained by performing them on the model.

- R20. *Creating required student actions by performing the actions*
  If a student is to be required to click on an object as part of the exercise, authoring that requirement should include clicking on the object. If the student is to change the state of a switch, then the author should be able to author that instructional step by clicking on the new switch position. As far as is possible, prompts to be presented to the student should be automatically composed rather than author composed. Naturally, additional features are required for letting the author interject additional explanatory materials, but much of the drudge work of building simple simulation exercises can be automated in a model-centered authoring system.

- R21. *Recording and restoring system states*
  To be contextually appropriate, many instructional sequences will require that the model be in a particular state when that instructional unit is presented. It should be a straightforward matter for authors to record such system states and to specify which one is to be used with each instructional unit. At presentation time, the recorded system states must then be loaded automatically.

- R22. *Automatic generation of common exercise types*
  Many types of exercises can be generated automatically, including identification and location exercises, exercises pertaining to functional causality, system operation exercises, indicator reading exercises, procedure exercises, and a variety

of fault diagnosis exercises. A powerful model-based authoring system should provide the tools for composing such exercises by simply indicating which parts of a device or procedure are to be covered. Such authoring tools should include prompts to the author, thereby minimizing the requirements for learning to author instruction.

- R23. *Free-play model-centered exploration*
  Once a working model has been developed, an author can make that model available to the student in a free-play mode, so that students can explore their understanding of the operation of the portrayed system.

- R24. *Building instructional templates*
  If a new kind of exercise is developed by the author that involves the repetition of a particular sequence of instructional item types, the author should be able to create an instructional macro or template that will automate the process of developing exercises of this new kind.

The Future of Model-Centered Computer-Based Instruction Requirements

As model-centered authoring systems are used to develop operator training, maintenance training, and system familiarization training courses, a number of additional requirements are likely to emerge. Some of these may include more built-in intelligence about the task requirements. For example, a model-centered system for authoring maintenance training could have a built-in expert that could evaluate the utility of diagnostic actions (Towne, Munro, Pizzini, Surmon, Coller, and Wogulis, 1990).

Future systems may be able to support more elaborate approaches to imaging and user interaction. In 3D graphics models, for example, there would be additional graphical primitive elements, such as rectangular prisms, cones, and spheres. These new types of elements would have additional intrinsic attributes that would permit control of their depth, their pitch and yaw, and their location in the Y plane of space.

More dramatically, virtual reality systems not only offer potential for 3D graphical attribute control, but also for enhanced user action. Using a data glove, students will not be restricted to clicking and dragging operations, as they are with a mouse, but will be able to grasp, push, and pull. Although these kinds of changes will call for enhancements in the graphical composition tools and in aspects of the behavior rule syntax, they should have less impact on the requirements for course planning and for instruction development.

ACKNOWLEDGEMENTS

IMTS was developed under funding from the Office of Naval Research, and from the Navy Personnel Research and Development Center, under contract N00014-87-C-0489. Development of RAPIDS was funded by the Air Force Human Resources Laboratory, under RICIS Research Activity No. ET 13 (NASA Cooperative Agreement NCC9-16). Our colleagues Lee D. Coller, Mark C. Johnson, Quentin A. Pizzini, David S. Surmon, and James L. Wogulis collaborated with us in the development of IMTS and RAPIDS.

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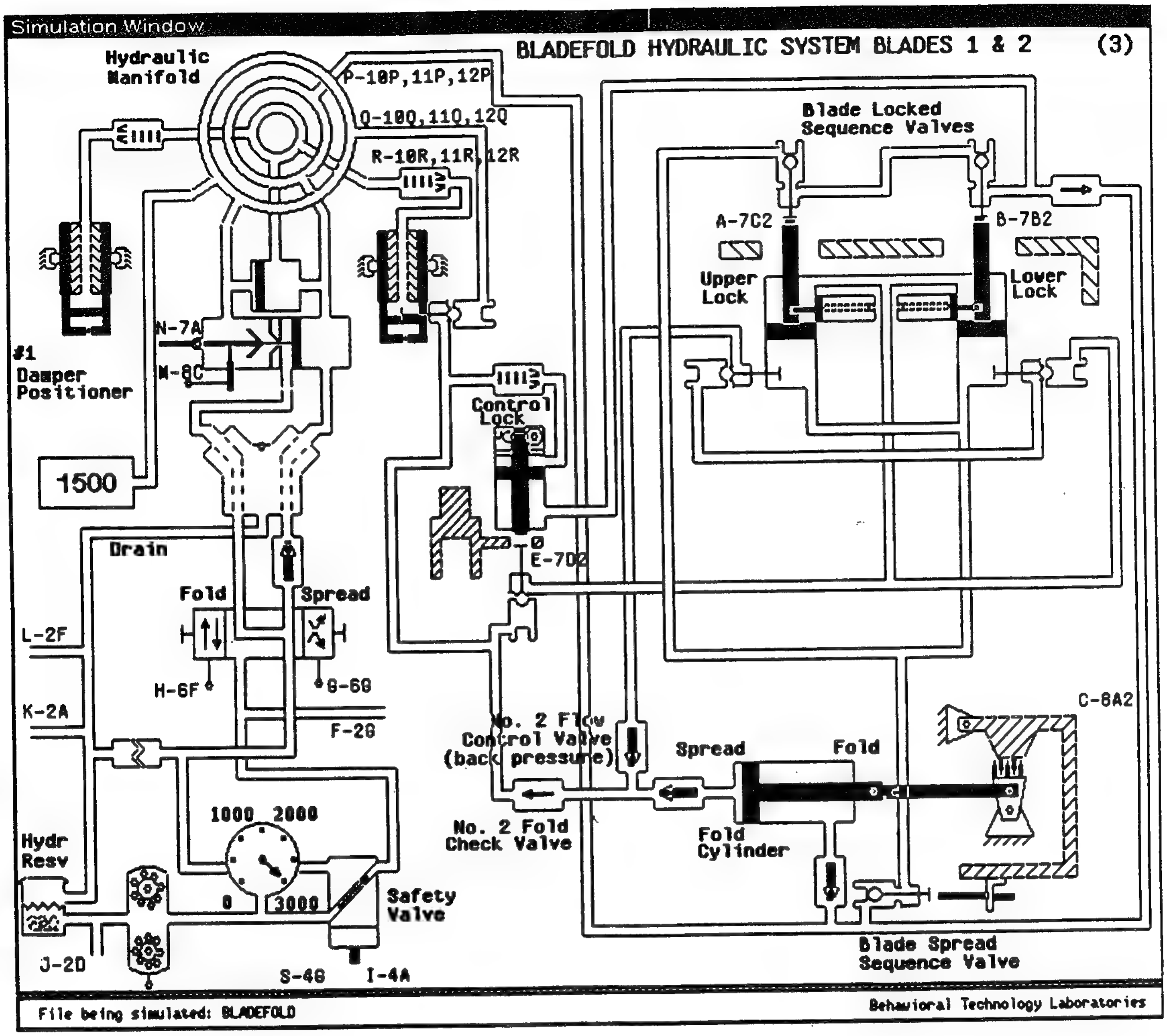

Figure 1. One of Fourteen Scenes in a Helicopter Bladefolding System Model

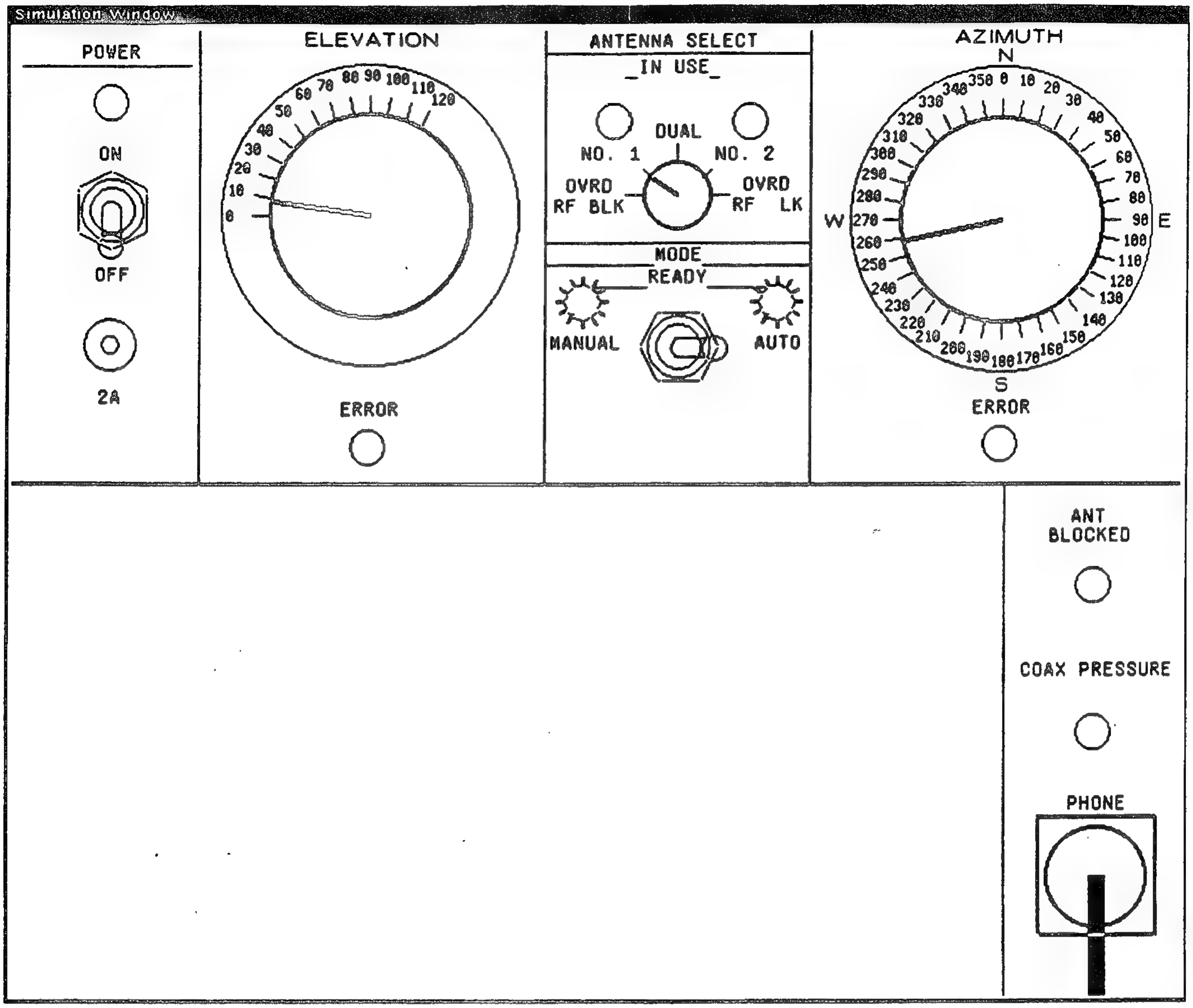

Figure 2. One Scene From a Satellite Communications System Model

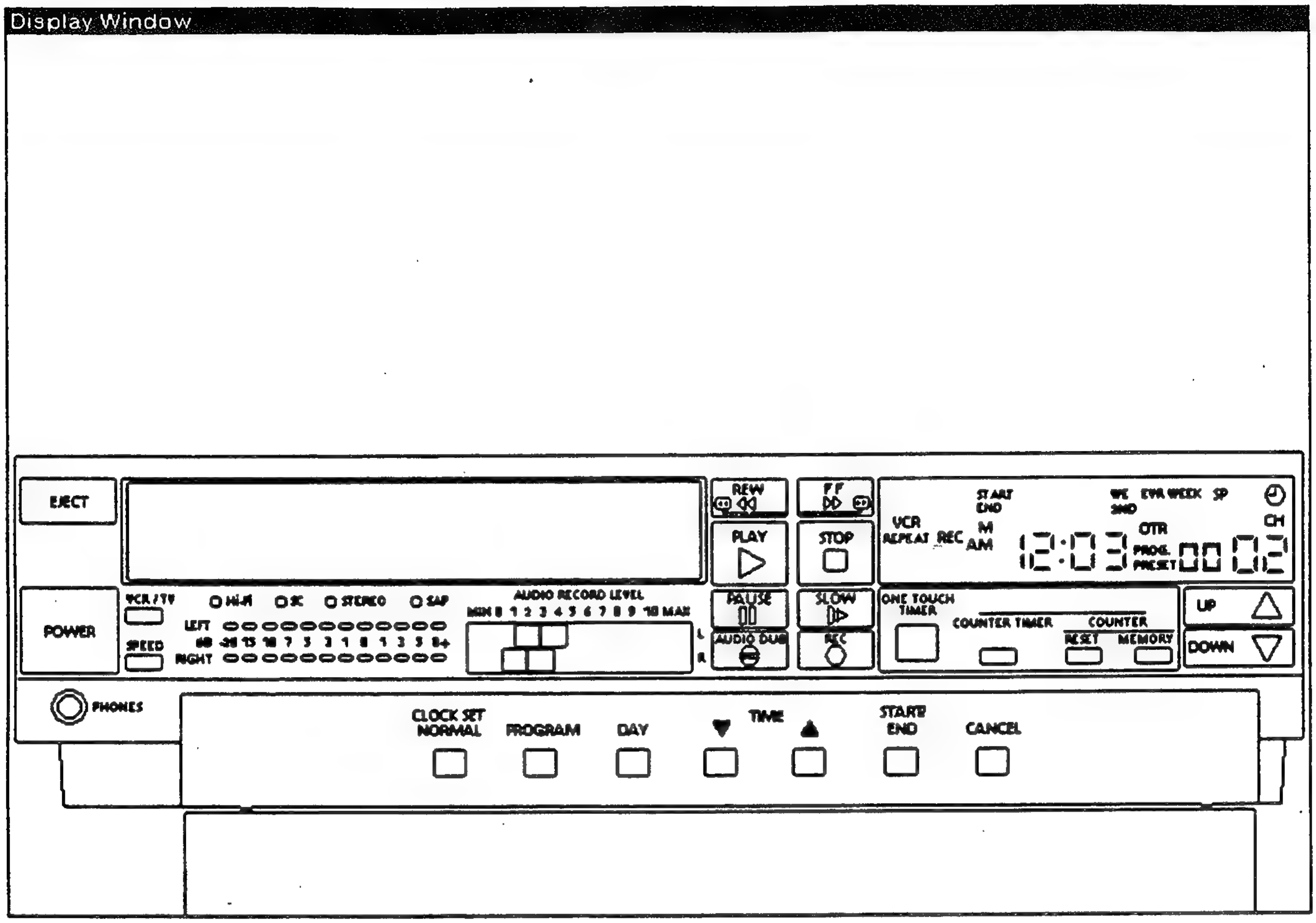

Figure 3. A VCR Front Panel Training Simulation

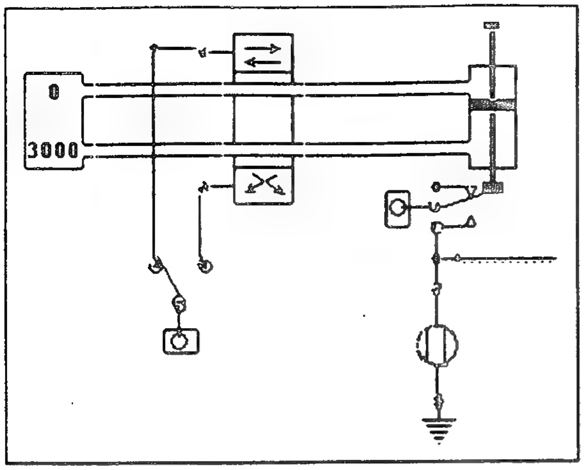

Figure 4A. Before Clicking the Switch

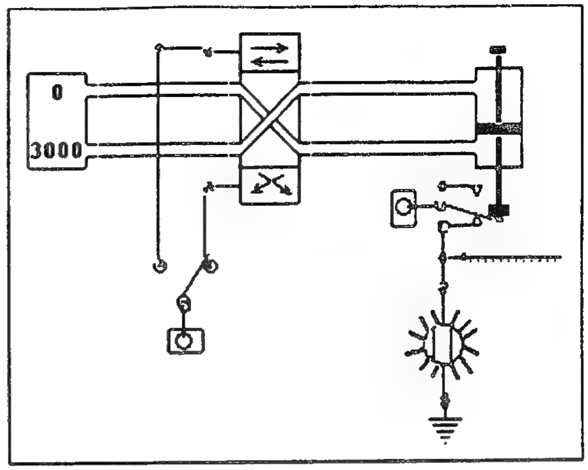

Figure 4B. After Clicking the Switch

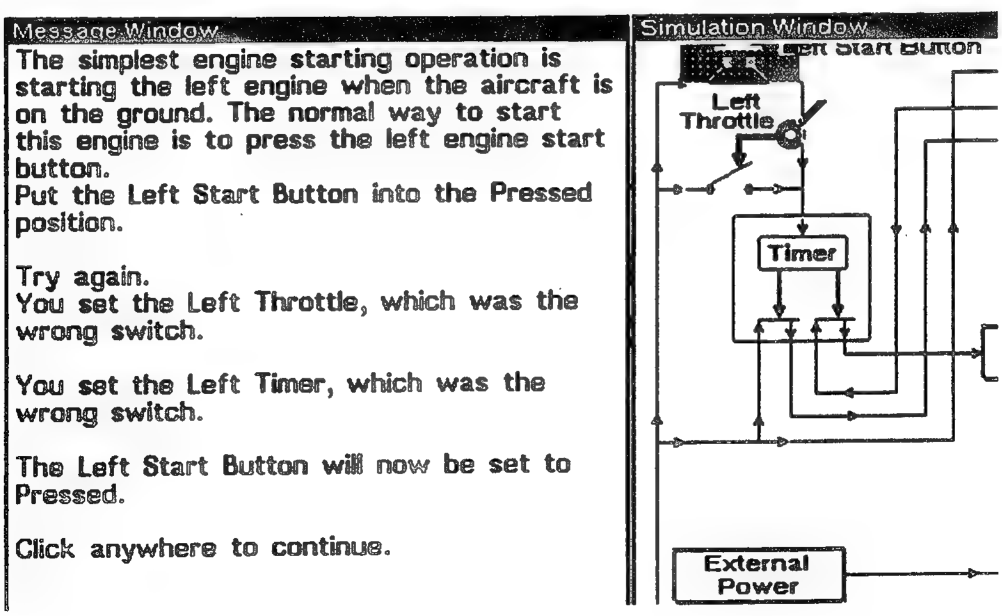

Figure 5. A Portion of the Student Interface During a Model-Centered Training Exercise

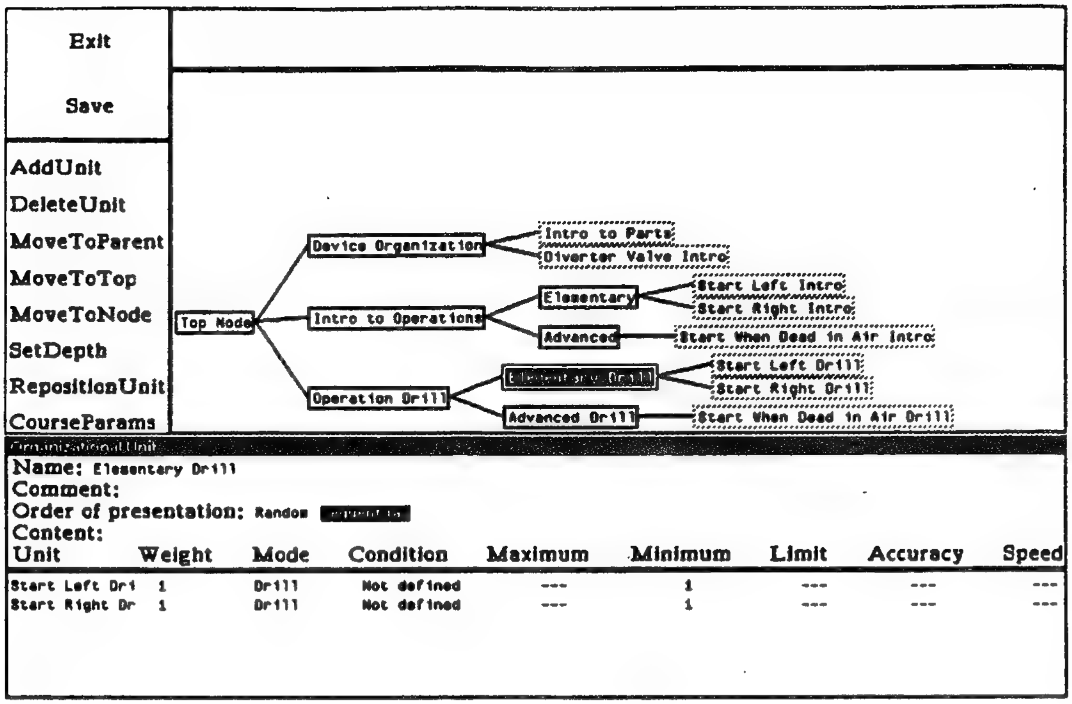

Figure 6. A Course Plan for RAPIDS

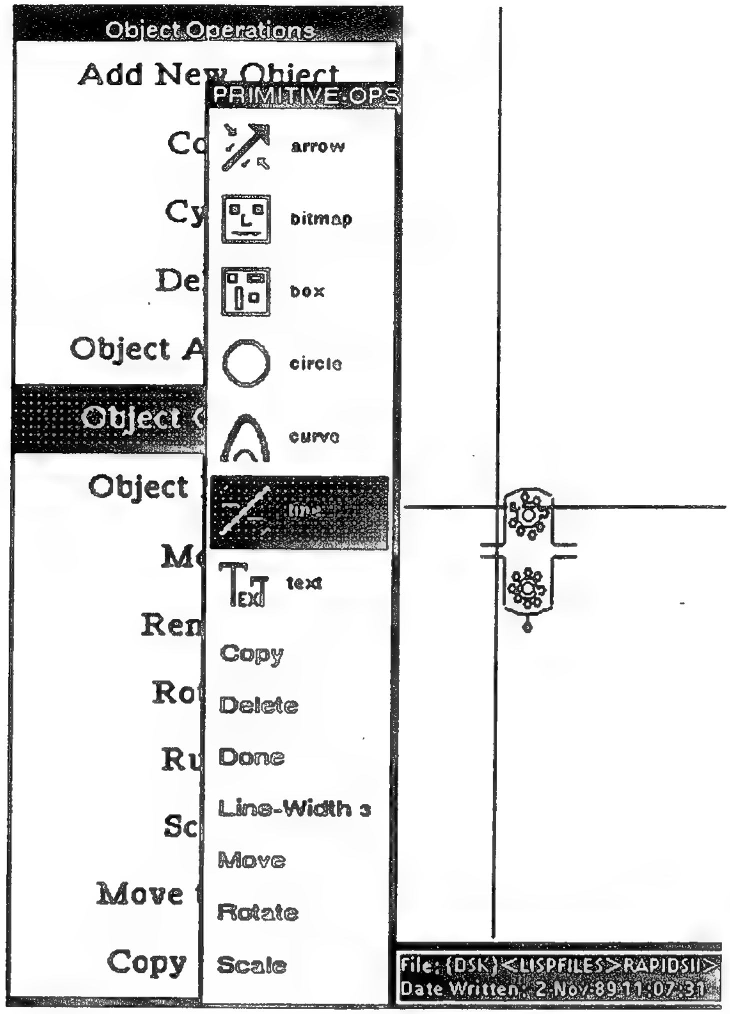

Figure 7. Drawing with a Palette of Drawing Tools

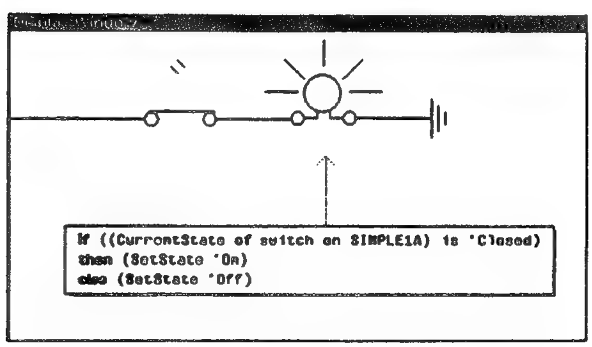

Figure 8. A Rule that Determines the Appearance of an Object

Micro-Video Display with Ocular Tracking and Interactive Voice Control

(Sensory Integrated Data Interface (SIDI))

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December 9, 1991

Abstract: An in-process effort to develop a highly miniaturized solid state computer display and control interface system is described. The system incorporates a micro-video display with ocular tracking on a lightweight headset and is controlled by voice commands from the operator. Various "off-the-shelf" components are integrated into a PC compatible computer along with a prototype hypertext software application to demonstrate conceptual capabilities. This effort is Phase I of Small Business Innovative Research (SBIR) Topic #N90-331 sponsored by the Naval Air Systems Command. The prime contractor is Foster-Miller, Inc.

Introduction

The last decade has produced an explosive growth of computer miniaturization technologies which continues unabated to this day. But while these technologies have reduced computer size and improved processor speed, memory, and software capability by several orders of magnitude, user interface improvements have been relatively few. Virtually all computer systems still rely on large and cumbersome interface devices - namely CRT/LCD screen displays and keyboards - with relatively little technological improvement over their 1950s predecessors.

In the case of certain space-restricted environments, such as submarines and aircraft, many of the benefits associated with computer technology have been foregone because of the size, weight, inconvenience, and power requirements of existing interface devices as well as the lack of mobility for the operators using them. The objective of this investigation is to integrate several new "off-the-shelf" technology products to produce a highly miniaturized, solid-state, micro-video computer display and control system which incorporates both interactive ocular tracking and voice control. Successful development will lead to the implementation of highly miniaturized and portable alternatives to currently used cathode-ray tube and liquid crystal display systems and keyboard control devices and will make the advantages of computer technology more applicable in space restricted environments.

Discussion

A number of newly emergent technologies are now available which can provide significant improvement for the human-to-computer interface. Each one of these technologies singularly can provide improvement, but significant synergy may be gained by combining several of them together into a single, integrated system. The goal of this project is to prototype four of these technologies into an effective interface system for the personal computer.

This effort will attempt to assemble an interactive interface consisting of a micro-video display in which screen cursor movement follows eye movement and menu function selection is implemented by voice command. The display projector/eye-tracker will be worn on a lightweight headset in a monocular arrangement with a small microphone incorporated for voice interaction. An existing hypertext software application, Computer Aided Fault Isolation (CAFI) for the Encapsulated HARPOON Certification and Training Vehicle (EHCTV) will be integrated with the hardware to demonstrate conceptual capabilities.

The newly developed technologies to be applied in this effort are those of micro-video displays, ocular tracking systems, computer voice recognition, and hypertext software applications. Based upon a survey of available products on the market, the systems described below have been selected for use in this project. High level diagrams of the integrated system are shown in Figures 1 and 2.

Micro-Video Display System

The system chosen to display computer data is the "Private Eye." The system consists of a small, matchbox-sized projector unit mounted on a lightweight headset. The projector is worn in a monocular position in front of one eye and interfaces to a standard PC computer data bus via an interface card. A virtual image of the computer CRT display is projected approximately 18 inches in front of the

viewer's eye with CGA resolution. A lens system allows image focusing to accommodate viewing with or without eye glasses.

Ocular Tracking System

The device chosen to provide an eye-tracking function for the display is the ISCAN Eye Slaved Pointing (ESP) system. It is available as a PC compatible, turnkey eye movement monitoring system that is designed as a hybrid interface device. Terminate and Stay Resident (TSR) software developed for the ESP is designed to substitute an operator's vision line-of-sight for standard pointing devices, such as a mouse or trackball, and provide positional data to an application which permits or requires a pointing device. The hardware functions by using a custom, integrated circuit chip set and tracking algorithms to follow a point on the eye in real-time. It accomplishes this by measuring and tracking a low-level infrared beam reflected from the eye surface. A miniature infra-red video camera is used to acquire the pupil and corneal images needed by the tracking algorithms. This tracking function allows movement of a screen cursor based on eye movement/position, that is, the cursor moves to where the operator "looks." Both the ESP and Private Eye are mounted on a lightweight and adjustable headset which can accommodate variable positioning of the components.

Computer Voice Recognition

The voice recognition unit chosen to provide voice interaction with the operator is the Convox Voice Master. The system consists of a control unit, speaker, microphone, and software which can provide both speech recognition and generation capability for a PC compatible computer using a RS-232 interface. The operator will use voice commands to implement menu options once the ESP has placed the display cursor on them for selection.

Hypertext Software Applications

An existing hypertext application developed by Naval Underwater Systems Center (NUSC) was chosen for implementation in this project. This application, Computer Aided Fault Isolation (CAFI) for the Encapsulated HARPOON Certification and Training Vehicle (EHCTV) was developed in Guide 2.0 (a commercially available hypertext development environment). The program allows the operator to access trouble-shooting data, schematics, failure databases, and repair procedures for the EHCTV by simply pointing and clicking on screen "buttons."

Project Status

Project work is in progress having been started in October 1991. The system base-line design has been established and hardware procurement is complete. Work currently underway includes development of special system software

device drivers, modification of the CAFI hypertext software application, and PC hardware integration. It is anticipated that the system will be ready for a preliminary demonstration at the Third Annual Airborne Weapons Technology Review and Training Exposition in January 1992. Plans are underway to proceed with a Phase II proposal for this project which will attempt to integrate the Phase I system into a transportable, belt-worn computer that will allow complete portable and hands-free operation (see Figure 3).

<u>Biographical Summary</u>

Mr. James E. Miller is the Encapsulated HARPOON Missile Program Manager at Naval Underwater Systems Center in Newport, RI. He holds a B.S. in Physics from East Tennessee State University (1978) and an M.S. in Ocean Engineering (1990) from the University of Rhode Island. A former submarine naval officer, Mr. Miller is heavily involved in the development of training material and computer based training systems for the submarine cruise missiles community.

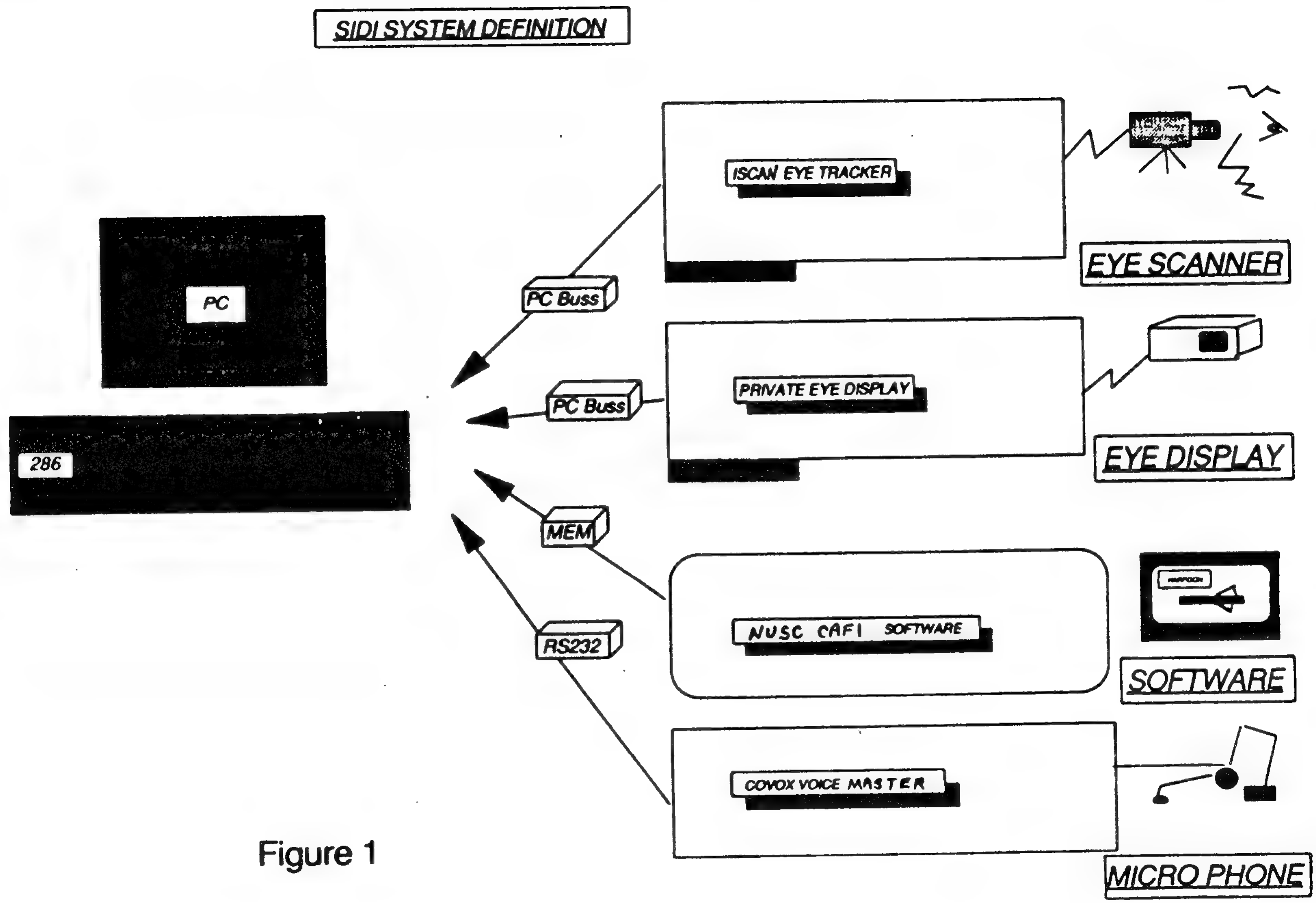
SIDI SYSTEM DEFINITION
PC
286
PC Buss
PC Buss
MEM
RS232
ISCAN EYE TRACKER
PRIVATE EYE DISPLAY
NUSC CAFI SOFTWARE
COVOX VOICE MASTER
EYE SCANNER
EYE DISPLAY
SOFTWARE
MICRO PHONE

Figure 1

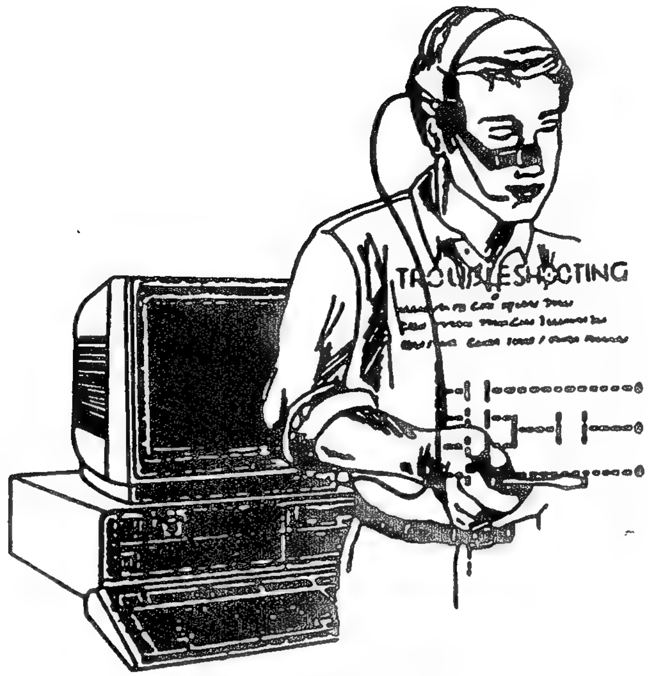

Figure 2

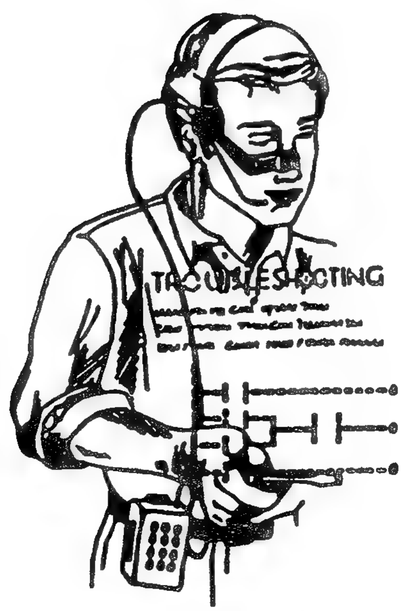

Figure 3

Tactical Naval Applications of Advanced 3-D Display Technologies

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Introduction

A group of rapidly maturing technologies are coming together to permit a new way of displaying and controlling information. The increasing speed and decreasing cost of high-resolution graphics computers is making it practical to generate complex imagery with acceptable realism in real time. Small high-resolution monochrome cathode ray tubes (CRTs) have long been used for military helmet-mounted displays. Liquid crystal displays (LCDs) with acceptable resolution are just now becoming available. Both are finding their way into commercial stereoscopic display systems. Commercial versions of position sensors developed for military head-trackers are becoming increasingly affordable, and their use has been expanded to create three-dimensional (3-D) controllers. Finally, the newest technology on the scene is digitally modified sound that presents the operator with realistic 3-D binaural hearing. These 3-D and other display technologies are being studied for their application to tactical Naval operations at the Naval Ocean Systems Center (NOSC). Among the potential beneficiaries of this technology are airborne early warning and forward air control, platform and force level battle management, air traffic control, compact flight trainers and mission planners, and many aspects of anti-submarine warfare (ASW). The mission area currently being investigated at NOSC is in the improvement of shipboard ASW sensor information displays.

Discussion

It is known that performance with displays improves when operator workload is reduced[1, 2, 3] and that this effect is amplified by prolonged operations.[4] This is because reduction in operator workload frees up cognitive resources which can then be applied to other tasks such as improved decision making.[1, 2] Therefore, displays which minimize this work load should result in improved operator performance and improved decision making. The need, therefore, is for displays which present information in ways which take advantage of natural human perceptual and cognitive skills. Few display systems in use today are more abstract than those used to support the ASW mission area.

Sonar displays have not changed significantly for roughly ten years. Existing ASW displays present information that is frequently truncated, altered, or otherwise simplified due to limitations in data processing, or the physical limitations of the display devices themselves. Currently, diverse sources of information must be correlated by the sonar operator who creates a mental model of the multi-dimensional ASW environment. The majority of this mental image must be derived from multi-dimensional acoustic, physical, and temporal information that has been presented in a

very abstract visual two-dimensional (2-D) format from a number of sources (Figure 1). This method of presenting complex, cross-sensory, multi-dimensional information on abstract 2-D displays may soon become obsolete. The application of new 3-D visual and audio display technologies to this problem could yield significant improvements in operator performance and operational effectiveness. These 3-D systems could present the critical tactical information in a far more intuitive and integrated way, thereby reducing the cognitive interpretation burden and learning time, while improving the tactical success rate over current systems. Figure 2 depicts the nature of the relationship between cognition, response time, and error rate. When the task of interpreting information is complicated, the response or reaction of the individual will be slower and the error rate will increase.

An advanced technology ASW display system could consist of, 1) the application of 3-D, stereoscopic, high-resolution, helmet-mounted or boom-mounted displays, 2) a 3-D position tracker (for the HMD) and 3-D manipulators for computer function control, 3) the incorporation of 3-D audio for presentation of multiple beams from the sonar for intuitive cuing and for correlation of acoustic transients and active returns to the ocean environment, and 4) the intuitive depiction of high-resolution computer-generated imagery of the ASW environment based on integrated display of active, passive, and environmental sensor information. The exact nature of the displays that may prove most effective are yet to be determined, but speculation unfettered by display constraints leads to some intriguing possibilities.

For example, in the active sonar mode the 3-D ASW display could provide the operator with a 360° field-of-regard image of the ocean bottom topography and water properties integrated with wave fronts representing the propagation of the sonar pulses (Figure 3). The operator would see these wave fronts being reflected off of the local topography and all known obstacles in that data base, and refracted by the model of the local water properties. The operator would therefore be able to see which returns are from known obstructions and compare that with the actual returns received by the sonar. Integrating this 3-D visual representation with acoustic analysis and cuing from the 3-D audio system would give the operator an intuitive picture of the ASW situation. Similarly, in the passive sonar mode the operator would be able to look around at real-time noise sources with cuing from the 3-D audio system (Figure 4). He could also view the sonar history over a desired time span for all bearings and elevations in a single 3-D volume (Figure 5). In each case any sonar beam could then be designated for spectral analysis.

Similar display approaches could be used for fixed site ASW facilities. Application of such a display system to airborne ASW is more challenging due to the strict size and weight limits of ASW aircraft, but computer size and weight are constantly decreasing. Many of the displays developed for surface ASW would be directly applicable to both airborne and ashore ASW. A few specialized displays may be added for such things as sonobuoy coverage however (Figure 6).

Significant enhancements to total system effectiveness could result, without redesign of other system components (e.g., sensors and sources of self noise). Recent experiments measured significant changes in sonar operator performance due to relatively minor modification of a standard sonar display.[5] These experiments were conducted under ideal signal-to-noise conditions and measured a multiple db loss due to a proposed fusion of data on a conventional ASW display.

As this research continues, new methods for presenting ASW information could arise that would make data relationships more apparent, increase situational awareness and enhance the quality of operator problem solving. This, in turn, may enable development of more sophisticated and effective tactics. Certainly, current tasks of target detection, localization, and classification would improve. Reductions in operator training and increases in retention could also be significant, and the effectiveness of each sonar operator could be multiplied as well.

This technology could also be applied effectively to ASW tactical support by providing the shipboard ASW officer (or submarine approach officer, Figure 7) with a 3-D image of the ocean environment, his weapons engagement envelops, sensor coverage volumes, and the hostile submarines that have been identified.

3-D display technology could also provide E-2C controllers with 3-D aircraft engagement information including launch envelopes, detection system coverage, etc. (Figure 8).

It could be applied to the display of battle management information (Figure 9) where location and status of assets determines weapons and sensor coverage.

A simpler application would be for air traffic control afloat or ashore (Figure 10) where only limited organic sensor information must be presented. Such a system might also benefit from the incorporation of real-time voice control of the communications system.

The Technologies

Four technologies are maturing sufficiently to permit a serious investigation of their operational use in an integrated information display system. They are high-speed graphics computers, miniature high-resolution displays, 3-D position sensors, and digital 3-D audio.

COMPUTERS

High-speed graphics computers are capable of generating acceptably realistic imagery that is updated fast enough to present an operator with useful information in real time. In the past, such capabilities were limited to massive and costly supercomputers. Fortunately the highly competitive nature of this industry continues to push cost down and performance up. Present high-speed graphics computers

surpass the performance of these older machines at a fraction of the cost and size. A few years ago a small computer that could run at 5 million floating point operations per second (MFLOP) and generate about 6,000 polygons per second was the hottest thing on the market. Today that would be a "low-end" machine. The "high-end" graphics computers today run about 30 times faster (180,000 polygons per second) at a comparable price. All of these machines are using multiple processors to achieve these speed and cost improvements with large supercomputers now operating with thousands of processors. The next ten years will see a continued increase in performance with a corresponding decrease in cost and size. Today's high-speed graphics computers will seem slow by the time a 3-D display system is ready to enter the Fleet.

DISPLAYS

Miniature high-resolution displays evolved from weapons control and sensor display requirements for military aircraft. Much of this work was pioneered at the Naval Weapons Center at China Lake under the AGILE Missile program and by the Air Force at Wright-Patterson AFB. Although the Navy fielded the first operational helmet-mounted display (HMD), the most widely used of these systems can be found aboard combat helicopters. These systems now use cathode ray tubes (CRTs) as small as 0.5 inches in diameter with 1,000 line resolution. Approximately 875 to 1000 line resolution is required for "seamless" imagery in an HMD with an average field of view. By way of comparison, a photograph is approximately 4,000 pixels high. All of these small CRTs are either monochrome or black and white. There appears to be a technology barrier against making full-color CRTs of this size, although there has not been a strong military or commercial requirement to push small color-CRT technology.

Small monochrome CRTs from portable TVs are in use in boom-mounted stereoscopic displays. Unfortunately, the process of magnifying the imagery from these CRTs for a stereoscopic display with an average field of view causes resolution problems. The use of standard TV technology (550 line NTSC video) results in very noticeable black stripes across the image due to the return stroke blanking used in conventional raster scan video. The use of high definition TV would reduce or eliminate this problem, but the day that such displays are available in the small-portable market is a long way off.

Color active-matrix Liquid Crystal Displays (LCDs) for the miniature TV market are now being used for displays in the majority of the commercial stereoscopic systems. These displays have recently doubled in linear resolution to the point of being comparable with standard television resolution (LCD image height of 480 pixels vs. 500 lines of raster-scan video for conventional TV). Although this is a great improvement over the previous generation of 240 pixel-high LCDs, this resolution is still low enough that the image appears very grainy when magnified as part of a stereoscopic display system. Unfortunately, higher resolution LCDs are not likely to emerge from the commercial market unless the demand increases by several orders of magnitude. The technology for creating a 1.0 inch diagonal 1,024 x 1,024 pixel active-

matrix color LCD is available, but the fabrication costs are estimated to be about $1 million dollars for the process development and production set up.

3-D POSITION SENSORS

The most prevalent 3-D position sensor system in use today is the Polhemus tracker. This device uses a magnetic field generator affixed to the local environment and a field sensor attached to the device to be monitored. A computer system monitors the field sensor and calculates the position and attitude of the sensor based on the nature of the portion of the magnetic field in which it is immersed. These units are small and rugged, but they are sensitive to the presence of ferrous metals which can distort the magnetic field geometry. Work is being done to reduce this problem and to speed up the operation of the system. Other position trackers are now reaching the commercial market however. One unit uses multiple ultrasonic sensors and sources to monitor position and attitude. An analogous multi-element infrared system is also available. These systems are not sensitive to electromagnetic interference, but they do have their own limitations. The Polhemus system is the only one that is currently incorporated into 3-D control devices.

3-D AUDIO

Of all the technologies that are supporting the ability to effectively display information in 3-D, this is perhaps the newest. It is an outgrowth of research into human auditory perception.[6, 7, 8] Initial research demonstrated the importance of the shape of the outer ear to the localization of sounds. Subsequently, the ability to modify sounds using experimentally derived transform functions was achieved. The transform functions were derived by measuring the distortion of known broad-band sounds due to outer ear shape. An undistorted sound, after processing by a transform function incorporated into circuitry, would seem to have emanated from any desired location. This made it possible to alter a sound so that it would seem to have come from any chosen location in space external to the listener. Recent work at NASA, Ames resulted in these transforms being incorporated into digital circuitry and married to computers that could simultaneously monitor the orientation of the operator's head (using a Polhemus tracker) and transform a sound so that it would seem to be stationary while the operator moved. NOSC has the first advanced digital system of this type and is conducting research into its application to various operational tasks.

Conclusions

These technologies are already being applied to numerous civilian tasks including architecture, mechanical design in the automotive and aerospace industries, pharmaceuticals research, medical imagery for 3-D display of CAT scan, NMR, and ultrasonic medical data, education, and functional aids for the handicapped.

If these new technologies are applied to the tactical Naval environment their impact on operational effectiveness could be dramatic and their impact on training methods and systems may be equally dramatic.

History has taught us that the requirement to operate a global Navy will not diminish at a rate commensurate with the decrease in our assets. Budgets and manpower levels will probably continue to decrease over the next decade or two. Therefore the workload for each person will increase, and the tactical cost of loosing one platform out of a reduced inventory will be magnified. Systems that can improve operational performance while requiring lower manning will be critical and those systems that can achieve the greatest performance improvements at the lowest cost will be essential.

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7. Wightman, E. M. & Kistler, D. J. (1989a). Headphone Simulation of Free-Field Listening I: Stimulus Synthesis. Journal of the Acoustical Society of America, 85, 858-867.

8. Wightman, E. M. & Kistler, D. J. (1989b). Headphone Simulation of Free-Field Listening II: Psychophysical Validation. Journal of the Acoustical Society of America, 85, 868-878.

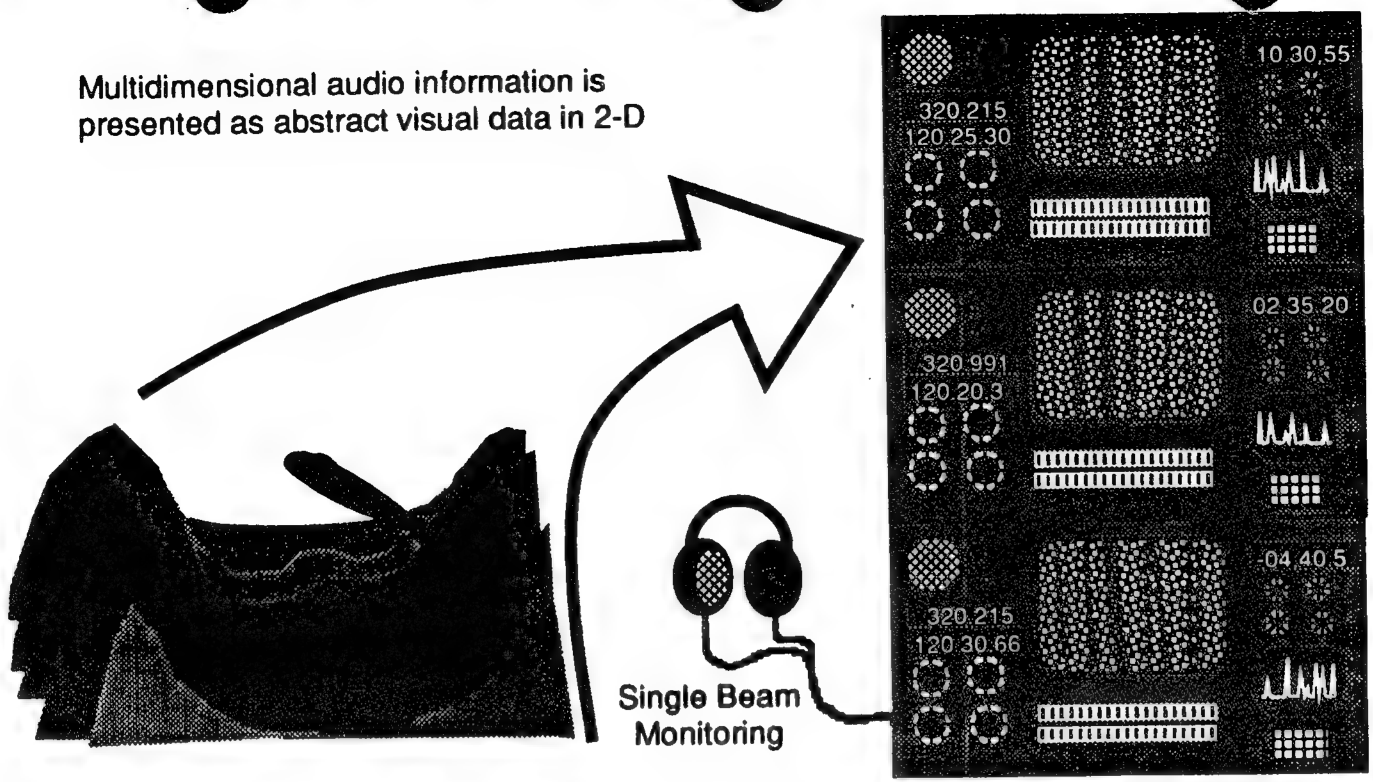

Figure 1. Existing ASW Display System.

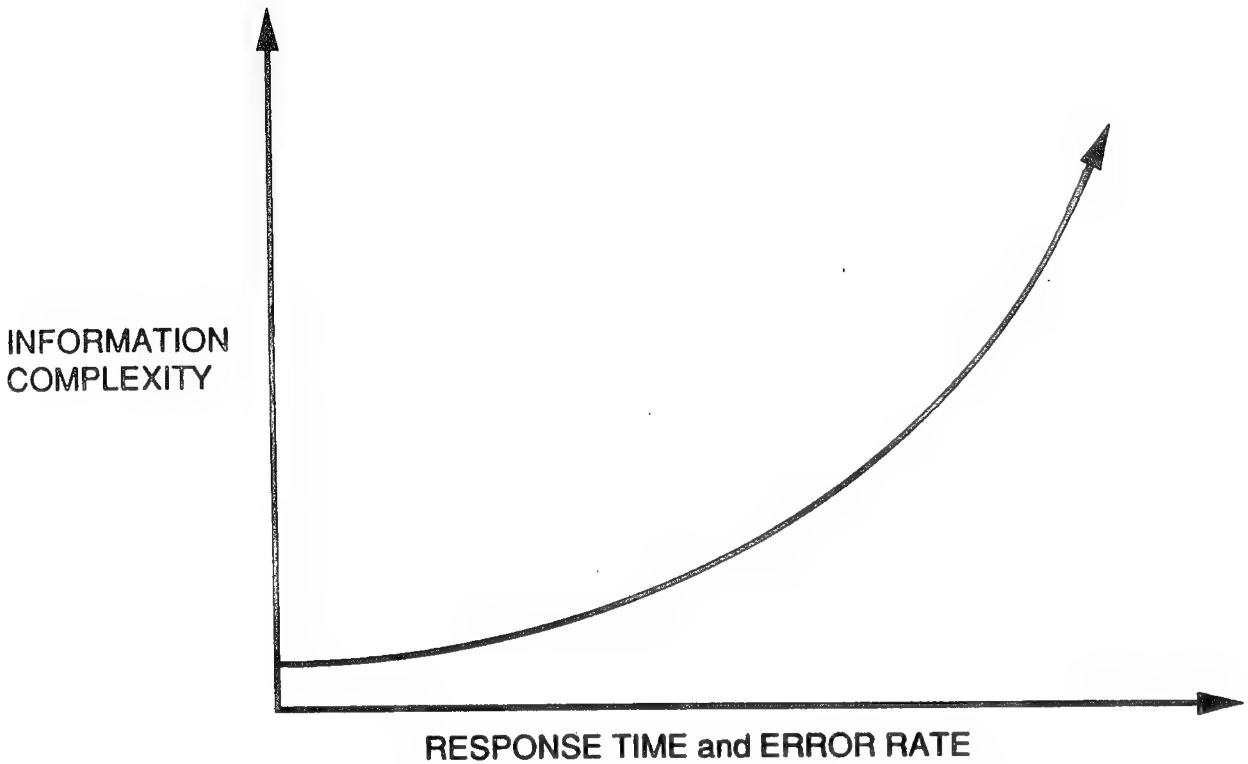

Figure 2. Relationship between information complexity and human performance

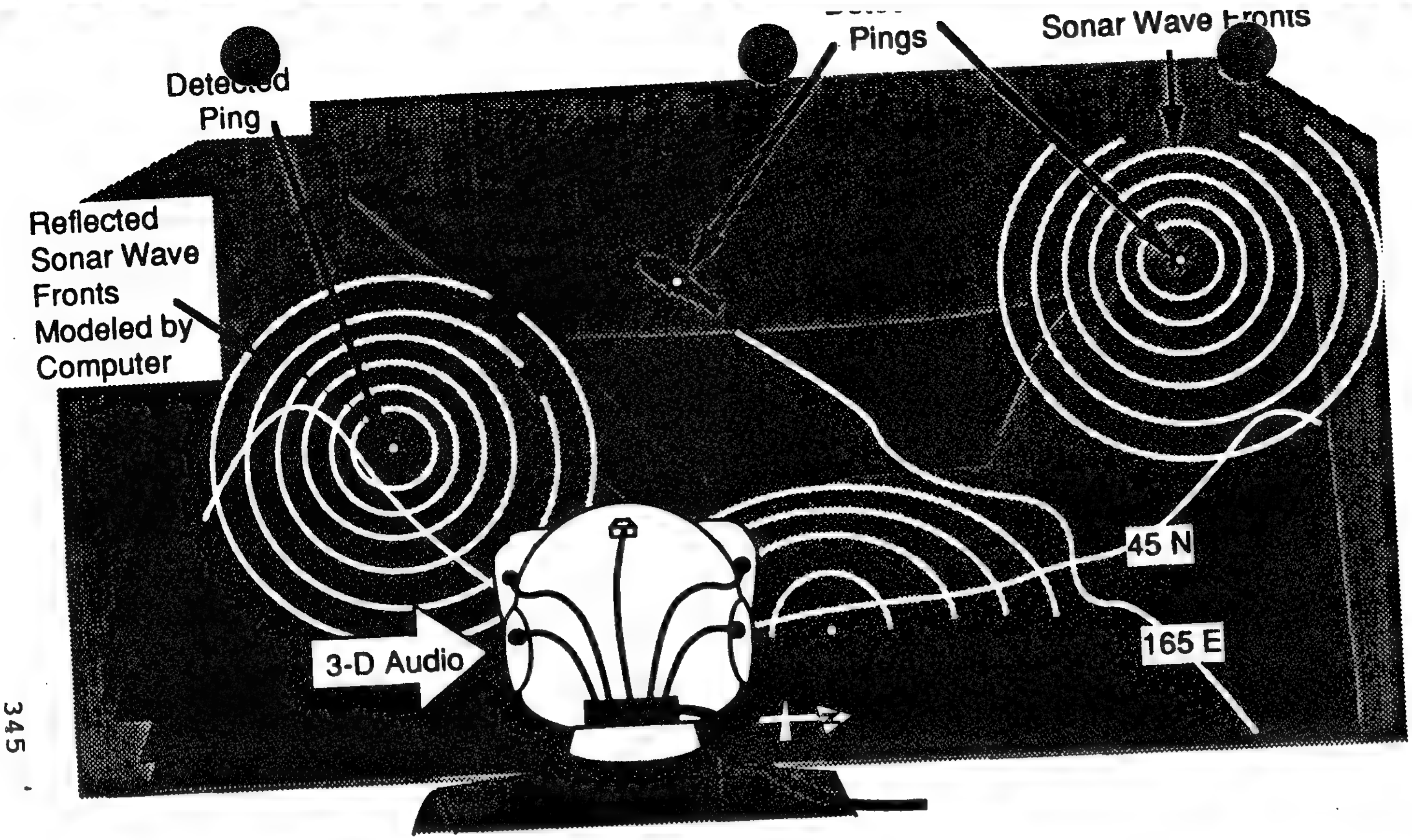

Figure 3. Possible 3-D Active Sonar Dislpay

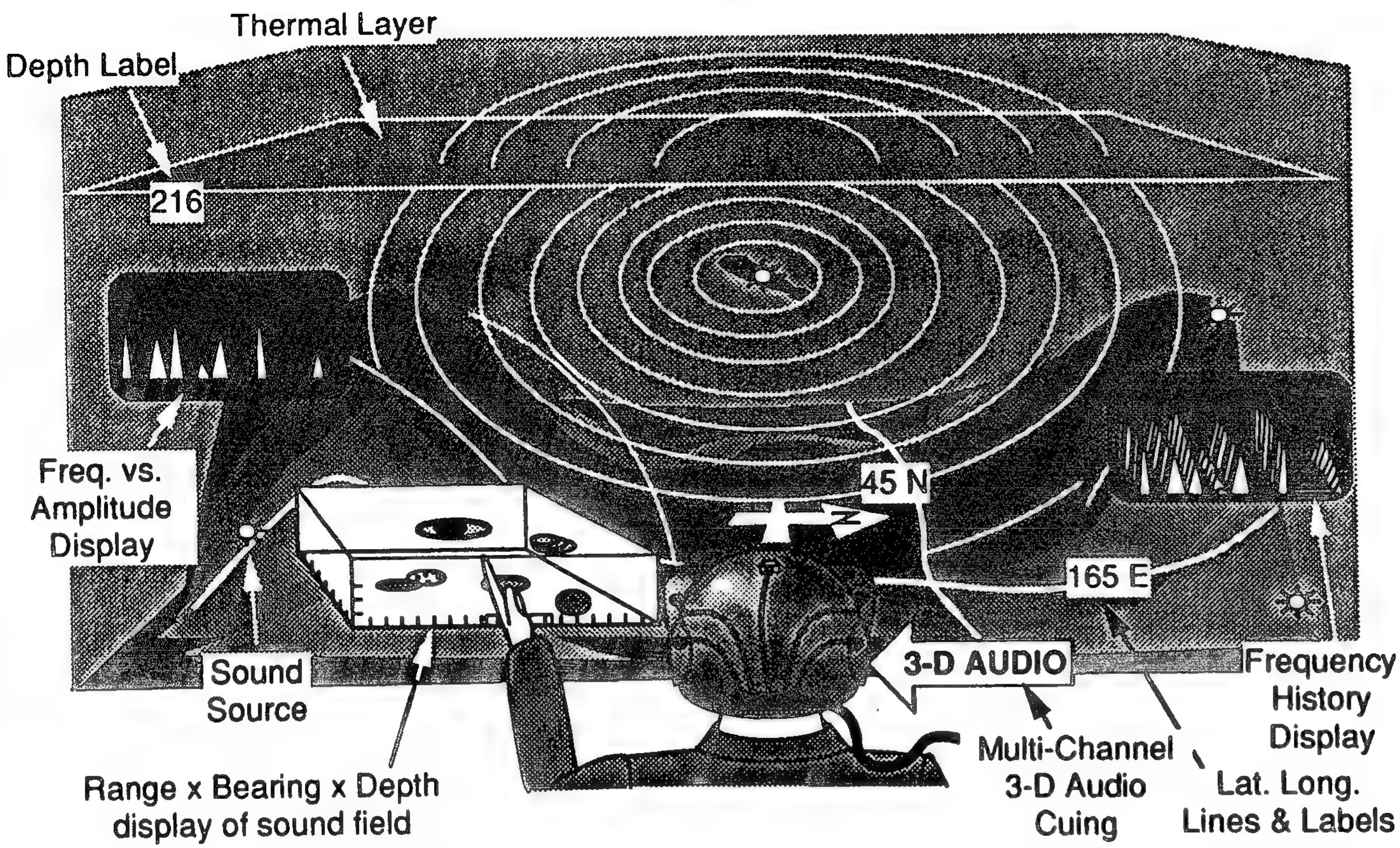

Figure 4. Example passive real-time ASW display.

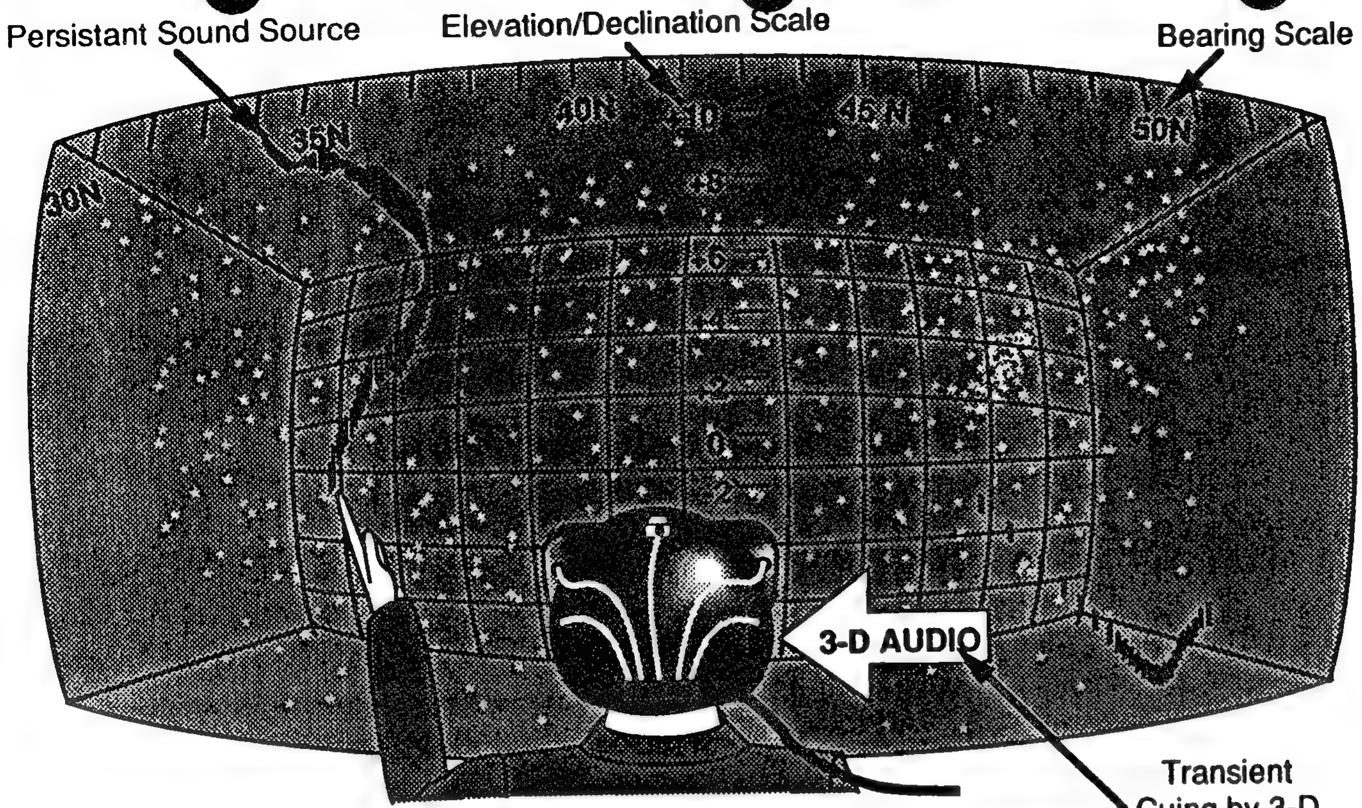

Figure 5. Passive Acoustic History Display
(older data is farther away & current data is in front at the grid).

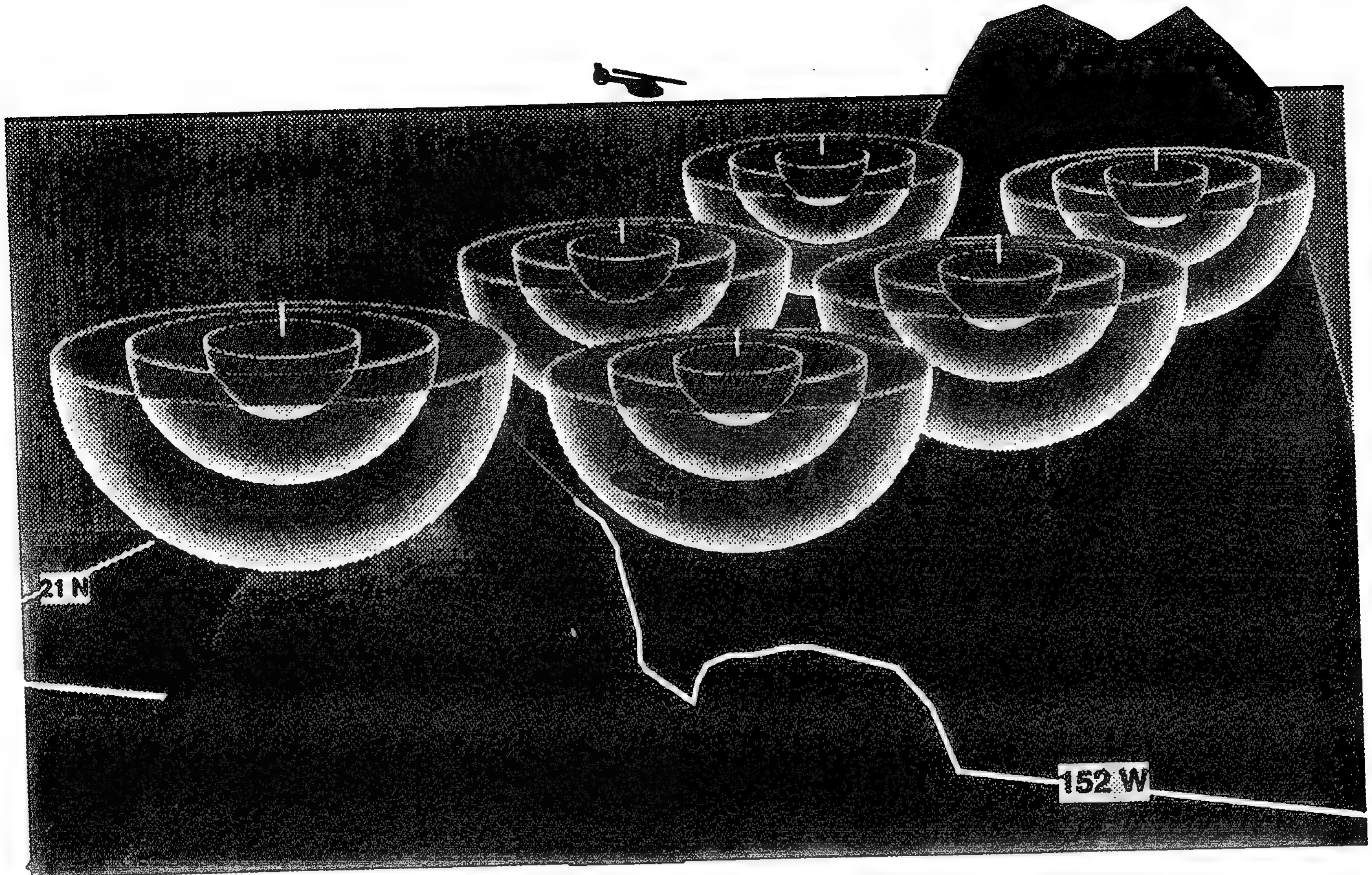

Figure 6. Example of a Sonobuoy Field Coverage Display

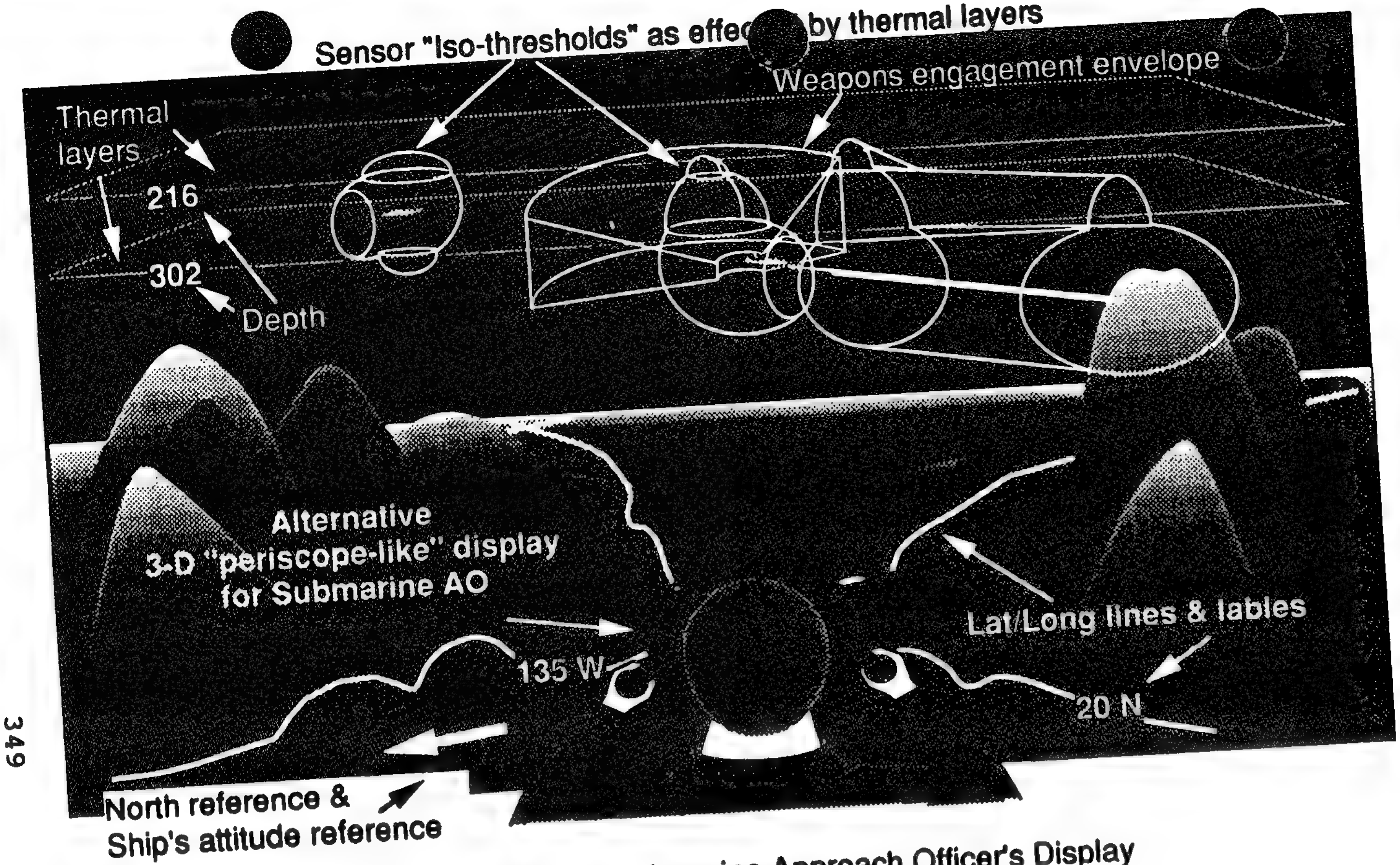

Figure 7. Example Submarine Approach Officer's Display

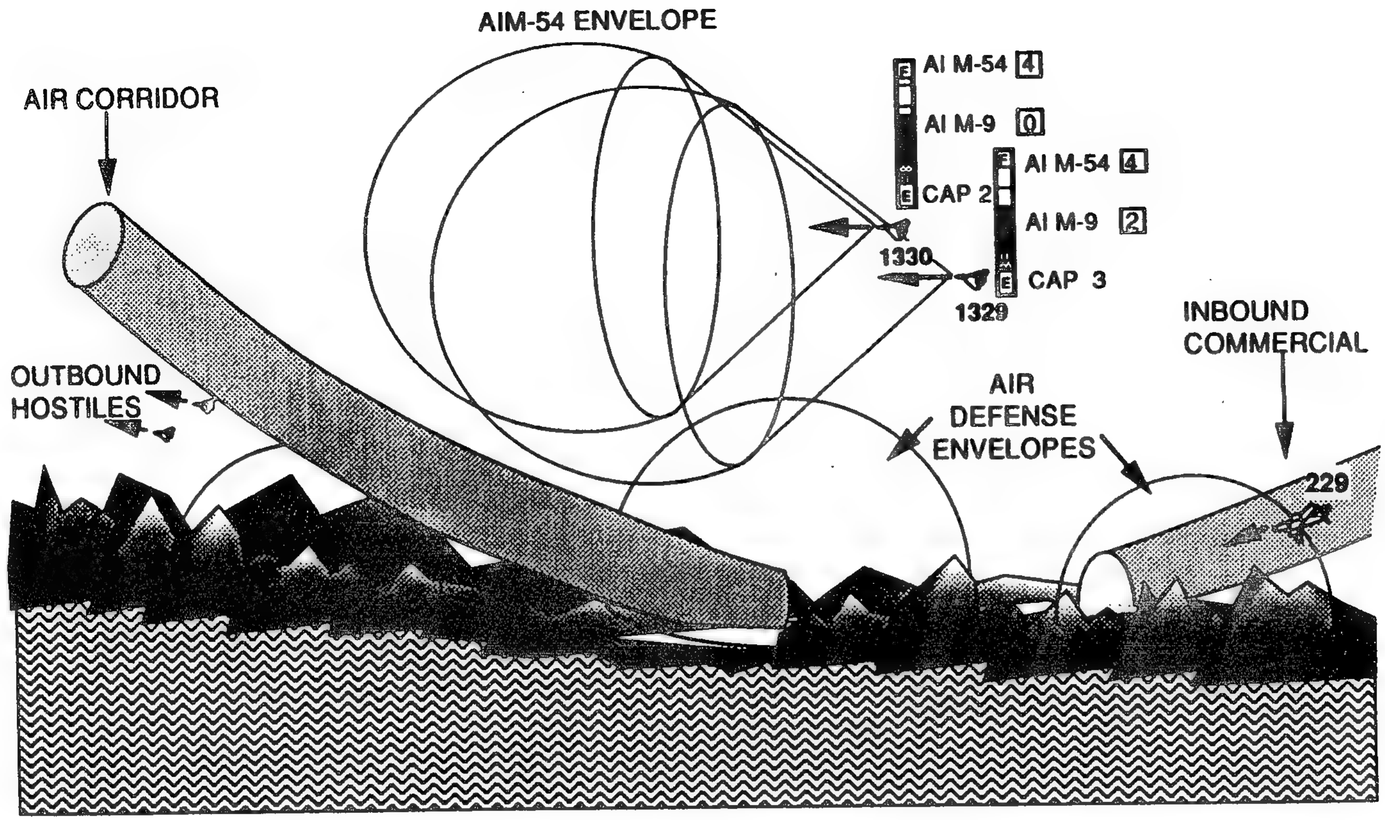

Figure 8. Sample AAW imagery aboard E-2C.

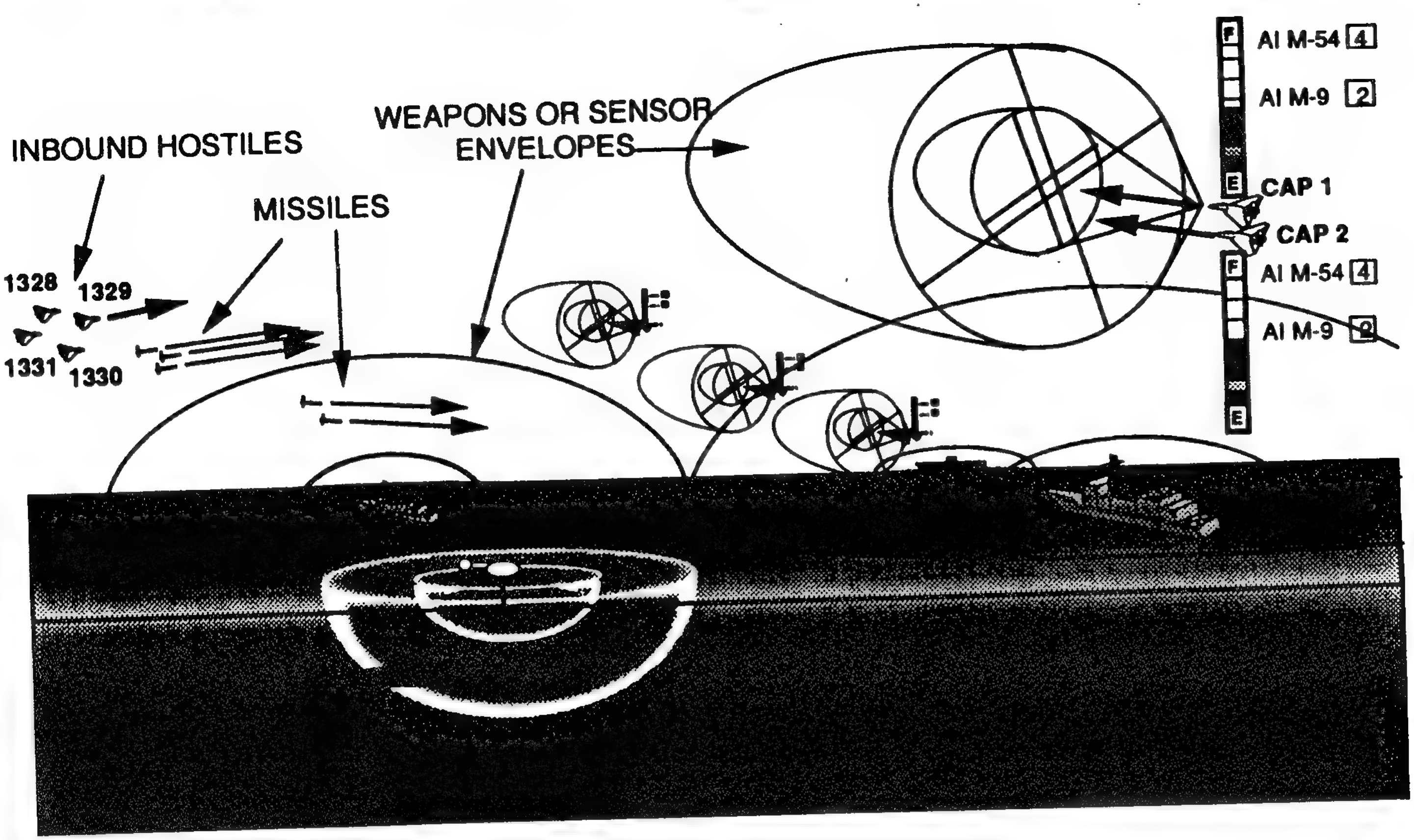

Figure 9. CVBG Tactical Situation Display.

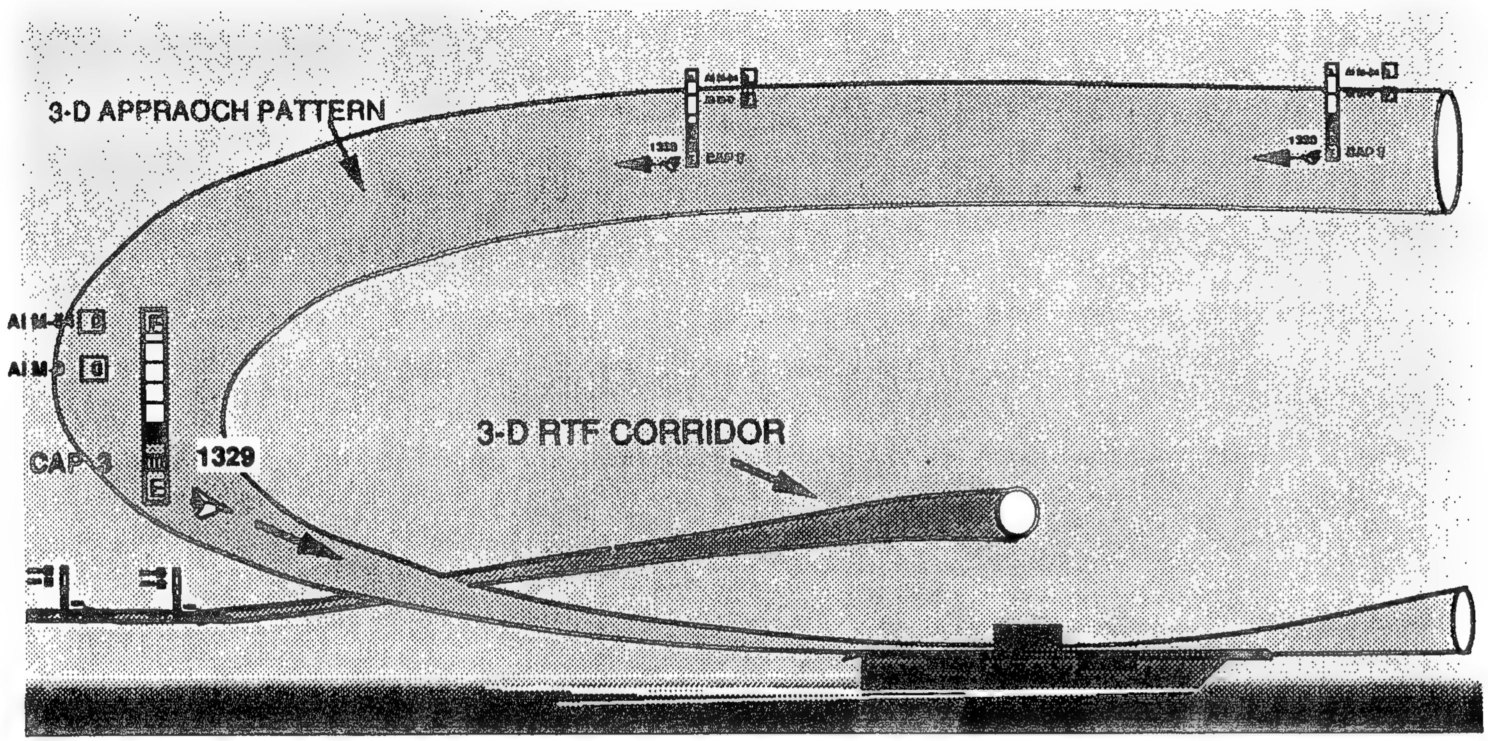

Figure 10. Sample Approach Control Display.

ARTIFICIAL INTELLIGENCE - EXPLOSIVE ORDNANCE DISPOSAL (AI-EOD) INFORMATION SEARCH, RETRIEVAL, AND DELIVERY SYSTEM

Paper Presented at the

THIRD ANNUAL AIRBORNE WEAPONS TECHNOLOGY

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Identification of specific equipment and software does not imply endorsement.

INTRODUCTION

The Artificial Intelligence - Explosive Ordnance Disposal (AI-EOD) information, search, retrieval, and delivery system project was a collaborative effort of the Navy Personnel Research and Development Center (NPRDC San Diego California; the Los Alamos National Laboratory (LANL), Los Alamos, New Mexico; and the Navy Explosive Ordnance Disposal Technology Center (NEODTC), Indian Head, Maryland. For further information see Conner, Madrid, Williams & Holland (1992).

Background

The size and complexity of the EOD mission continues to increase. The performance of the EOD technicians is dependent on the information support system. The military EOD community consists of approximately 3000 joint-service military personnel who respond to over 20,000 operational tasks each year. Increasing sophistication and complexity of munitions, their incorporated countermeasures, and the acquisition and fabrication of munitions by third world nations and terrorist groups further tax the skill and training of the EOD technicians.

The Series 60 publications, called Technical Orders (TOs), used by EOD technicians have over 117,000 pages in 28,000 separate documents and include 25,000 diagrams and photographs. The 13 subcategories of ordnance, each with different identification features, must be familiar to the EOD technicians. Candidates who possess the aptitude for the EOD field is decreasing, and the number of experienced technicians retiring is increasing, as the need for EOD technicians increases.

Problem

The current microfiche-and-paper-based information system is difficult and confusing to use. Difficulty of retrieval of information in the field and in transporting, searching, updating, and validating the microfiche and paper documents is said to be a major cause of attrition (25%) and setbacks (52%) in the school and of reduced performance in the field. Each year the NEODTC issues about 200 revisions to the Series 60 publications. Keeping the publications up to date is an error-prone and labor intensive chore.

Purpose/Goals

The purpose/goals of the AI-EOD effort were to develop and evaluate for procurement a computer-based technical search information and retrieval system to: provide EOD field units with search techniques, identification aids, information, imaging, and communication capability to improve the identification speed and accuracy, and reduce casualties; to automate the distribution of technical information to and from EOD operational forces. Anticipated improvements were to (1) provide EOD technicians with an efficient, easy-to-use information delivery system for identifying ordnance and retrieving the appropriate render-safe procedures (RSPs) (reduce time by 30%, identification errors by 20%, and RSP errors by 30%) and (2) reduce the level of experience required for competent performance, reduce casualties, increase number of EOD technicians by reducing requirements, reduce career and school attrition and setbacks related to the current system, and improve accomplishment of EOD tasking (enhance active and guard/reserve skills).

Products/Deliverables

The AI-EOD effort resulted in a Requirements Analysis, Database Technology for converting the EOD database, Test and Evaluation Results, recommendations for an Electronic Distribution System, and input to a Procurement Specification (Development Option Paper).

AI-EOD SYSTEM FOUNDATION

Previous Expert System Approaches

Previous prototypes using expert system approaches have been able to extract the expertise for a few identifications. The complexity level of this approach was high and growing quickly and the expertise had to be incorporated directly into the software code. Incorrect, ambiguous, or new information would invalidate the expert system. The effort of creating and maintaining an expert system could not be sustained. A method had to be found to deal with the problems of working with incorrect, incomplete, or ambiguous information.

Neural Network Design

The foundation of the AI-EOD system (hereafter called AI-EOD), the "neural network," is modeled after neurological processes and represents an innovative implementation of AI. The result uses any combination of available criteria, including incomplete, inaccurate, or negative data as well as phonetic searches, to access the EOD publications (Conner et al., 1992).

AI-EOD SYSTEM PROTOTYPE DESCRIPTION AND OPERATION

The AI-EOD prototype is an AI-based multiple-incident identification, recording, and tracking system featuring state-of-the-art image and text management.

The prototype system was written under the UNIX operating system using X-Windows. For speed of development and use of available software tools, the prototype was developed on a Sun 4 SPARC workstation. The UNIX operating system is POSIX compliant. The X-Windows graphical user interface (GUI) uses the Open Look presentation style. Application software was written in the C language. To ensure portability, only standard library calls and conventional programming protocols were used. The AI portion of the code, the neural net, was written in C++. The input data are expected to be straight ASCII files.

Software

The software is separated into two major areas:

1. The operating system, which manages the logical and physical resources of the computer.
2. The application software, which uses the resources of the computer to achieve the users' goals.

Operating Systems. Requirements of the AI-EOD prototype were that the system must be POSIX compliant and use X-Windows. The POSIX standard basically prohibits the use of nonstandard or machine-specific programming practices. The UNIX operating system meets and provides a medium for this standard.

Presently, DOS cannot handle X-Windows directly. However, the same look and feel can be achieved by the use of Windows 3.0. The lack of virtual memory management by DOS can be overcome by the use of certain utilities incorporated during the design of AI-EOD. Building a DOS-based version of AI-EOD system has the advantage of utilizing the many DOS machines currently in use by the EOD units.

Application Software. Thousands of lines of code are involved in creating the user interface. The interface is what the user 'thinks' is the system. It is imperative that a dynamic graphical user interface (GUI) be provided; X-Windows provides a means to present a dynamic GUI which the AI-EOD system must have. The user should not be forced to proceed with a rigid sequence of questions and answers. The EOD technicians must have the ability to respond to the given situation with the information available. No attempt should be made to second guess the procedure necessary to solve the EOD technician's current situation; that is, do not construct the 'best way' to proceed, rather provide as flexible and individual approach as is possible. The GUI must present the user with a variety of options, none of which should be mandatory. Choosing a particular option will cause the presentation of the next set of related options, gradually narrowing the area of interest and answers.

Imaging. Because the input by the EOD technician will result in the presentation of images of the selected publication, the AI-EOD system must have the following features:

1. The software that renders the images must be fast, non-memory intensive, and machine independent: CCITT group 4 data compression is recommended.
2. The software must provide for the ability to zoom in on the area of interest.
3. Selecting the area of interest must be either by drawing a box around the area of interest or selecting the center point of zoom perspective.
4. The user should be able to modify the zoom ratio.
5. Zooming out should reduce the total image at least to 25% of its normal size.
6. Zooming in should continue until straight lines are stairstepped from pixel blow up.
7. The images must be window based.
8. The user must be able to adjust the size of the windows; both horizontal and vertical scroll bars are necessary to facilitate the adjustment of the image within the window.
9. The user must be presented with multiple image windows, each identifying the publication and image number.
10. Users must be able to rotate the image in the image window in increments of at least 90 degrees.
11. The option of providing a mirror image of the image is desirable.
12. The user must be able to return the image to its normalized view in a single step.
13. Each image must be capable of being printed.
14. The printing options must include printing the portion shown in the window, the full image, or the entire document.

Raster Format. The AI-EOD prototype uses raster format, which stores the image as dots, called pixels. There are approximately one million pixels per image. The CCITT group 4 compression standard will reduce the storage requirement significantly. Raster scanning will save the entire page--words, drawings, and the white space. It is assumed that vector graphics and special text handling (SGML) would be used in an implementation system.

AI-EOD System Operation. A prime consideration in the design of AI-EOD system was that users should require little or no training to be able to use the system. Based on X-Windows, the system will accept data input from selections made form various menus. As the keyboard is used only for entering numeric data or searching for specific words, EOD technicians can wear protective clothing while using the AI-EOD system. Since operation is restrict-

ed to the current menu options, no previous knowledge of computers, or the design and philosophy of the system is necessary.

Category Search. The program begins by presenting the main window to the user. All options are presented as buttons and are selected by a mouse. Drawing upon the EOD training, there are 13 buttons--each is labeled for one of the ordnance categories. The EOD technician first categorizes the unknown ordnance. Selecting one of the buttons invokes the expert system knowledge that presents a window with a list of identifying attributes relevant for that ordnance category. The EOD technician is not required to enter any information for a specific attribute. Depending on the situation, the EOD technician can enter as little or as much as is known or useful in identifying the ordnance.

Selecting a specific attribute may cause the system to ask additional questions. These additional questions will appear in smaller windows that simply "popup" on the screen. Except when requesting numerical data, nicknames or title words, all pop ups or windows provide a restricted list of acceptable responses. These options reflect the terminology and training of experienced EOD technicians.

If the list of attributes presented is not appropriate for the device in question, the user can return to the main window, select another category, and begin again. Since many devices share attributes, the same attributes may appear on more than one option menu. For example, if the ordnance is a rifle grenade but the user selects the mortar category, many attributes will be listed that can be used to describe the rifle grenade. Obviously, the rifle grenade will have attributes that are not available on the mortar options. If this occurs, the EOD technician will realize that, since this attribute cannot be described in this category, the category is wrong.

Internally, the neural net will not restrict itself to the category chosen. The attributes described will be used to search all ordnance to compensate for both the inexperienced EOD technician, and blurred distinction between categories.

When a window appears, the user is not compelled to respond to it or any other window. Each window will remain visible until dismissed or answered. Each category window includes a panel which displays all of the attributes and their values entered by the user. The main window also contains a subwindow that can be used by the EOD technician to record events relevant to the mission (incident). The system can maintain information for up to 10 missions simultaneously.

The user can use the entered information to "search" at any time. The neural net will use all input information to produce a list of candidate Series 60 publications. A separate window will open and present this list in descending order according to how closely the device matches the entered characteristics. This window shows the title and indicates the strength of selection for each piece of ordnance (based on how closely each matches the entered characteristics).

Selecting any of the listed items will open a window that displays the contents of the publication. This image can be manipulated to step forward or backward, page by page, through the publication or to jump directly to a particular image. The user can zoom in on (enlarge) or zoom out from (reduce) the full image or any portion. The image selected can be rotated by 90 degree steps or presented as a mirror image. The window showing the image can be shrunk or enlarged. Additional image windows can be created by making additional selections from the candidate publications window. Each image window is independent and can be used to step through and compare images from the same or different publications.

Neural Net Reasoning. Instead of viewing a particular Series 60 publication, the EOD technician can request that the system explain its reason for including that publication on the candidate list. A window will open, show the publication number, title, and selection strength. Next, a list of the attributes that were used in the selection of this publication and a numeric value showing the relative influence factor of each attribute will be displayed. This section of the window shows the reason for placing this publication on the candidate list. The summation of the individual attributes determines the position on the candidate list.

The list also includes the rest of the attributes that identify this ordnance and can be used to confirm the identification or show that the publication does not agree with the target ordnance. This list can also be used to suggest additional attributes to enter to aid in further searching.

After a publication is selected, it may be printed. The 300 dot per inch (dpi) printer produces copies that are indistinguishable from the original paper publication. The system can print the full document, the page being displayed, or only the zoomed portion of a page.

Publication Number Search Option. In addition to the 13 ordnance categories on the main window, the AI-EOD system has other options to aid the EOD technician. Many ordnance devices become well known to the EOD technician. Rather than force the EOD technician to enter descriptive attributes, there is an option to enter just the publication number. The Publication Number Search Option opens a window that displays a list of all Series 60

publication numbers and titles from which the user can select directly. Alternately, there is a place to enter the publication number, or parts of the publication number. Entering a complete or incomplete publication number moves the focus point to that portion of the list. Knowing the logic behind the publication numbering scheme allows the user to move quickly to the section of the list of specific interest. Selecting from this list presents the document in an image window.

Unknown Category Option. If the user does not know what category to classify an ordnance into the Unknown Category Option provides an alternative approach and when selected will present several windows. These contain all of the known questions and attributes that can be used in identifying an ordnance (without regard to category):

1. The Dimensions Suboption presents over 40 possible measurement methods. The technician can select any that make sense for use with the unidentified ordnance.
2. The Quantities Suboption displays more than 20 items that can be counted (e.g., how many fins are there).
3. The Features Suboption displays more than 50 selections that can be made according to whether or not it HAS a feature (e.g., does the device have fins?).

Any question that can be used to identify any ordnance appears here. By using this main window option, Unknown Category, false starts created by inexperience or the blurry distinctions between categories can be avoided.

Fuzzy Word Search Options. The Fuzzy Word Search Option (Nomenclature, Title, or Common Name) opens a window in which the user can enter one or more words to look for in the title. Common names or aliases which the expert system collected during data collection are also searched. The neural net presents the same type of candidate list of publications as presented by an attribute search. This option will provide a "best fit" listing of all the titles that are close to the entry, even if the original input is misspelled.

Foreign Language Terms Option. The markings and terms printed or stamped on an ordnance can be used in fuzzy word searching if they are in English. The situation is more difficult if the markings are in Cyrillic, Arabic, Chinese, Japanese, Korean, or any other nonalphabetic-based language. Selecting the Foreign Language Terms Option causes a list of languages to be displayed. Selecting a language presents a window that displays foreign language terms and their English equivalents. The user can find the English equivalent by matching the appearance of the markings to the images. These terms can then be used in the fuzzy word search or to select a specific category.

Hardware

The following lists the general hardware configuration that was used in the prototype (as modified based on interim results from testing and user feedback) and is recommended for the AI-EOD system (see Conner et al., 1992, for further information):

- Monitor. Color monitor with intensity and contrast controls, and with at least VGA clarity.
- CPU. Minimum 386, or equivalent, CPU. A 486, or greater, CPU is recommended for greater power and speed. A math coprocessor is suggested but not required.
- Main Memory. Minimum of 8 megabytes of main memory; 16 megabytes is suggested.
- Operating System. UNIX Operating System with X-Windows or alternatively, DOS 5.0 and Windows 3.1. While the neural net code for the UNIX and DOS versions would be identical, the code for the user interface would not be compatible and is nontransportable from one system to the other.
- Application Software. Expert system for database collection about each ordnance (identification-table construction-query system) and an X-Windows-based graphical user interface using the knowledge from the expert system to direct the design. Neural net-based retrieval engine.
- Hard Disk Drive. Minimum 400 megabyte hard disk drive, or at least 100 megabytes greater than that required to store the operating system and X-Windows.
- CD-ROM player. Standard CD-ROM player using ISO 9660 file format.
- Image Storage. CCITT group 4 raster image storage.
- Printer. Laser printer (or equivalent) capable of printing 300 dpi or better at a minimum rate of six pages per minute with an additional 1 megabyte of local printer memory for image printing.
- Graphical User Interface (GUI). Open Look, or similar, desktop screen environment to facilitate the use of the AI-EOD system with other software used by the EOD technician.
- Input Device. Mouse, trackball, or joystick.

Summary of System Capabilities

Artificial Intelligence. The neural net, which is the foundation of AI-EOD, follows actual neurological processes in the implementation of artificial intelligence. The prototype system is an information search, retrieval and delivery system that uses a combination of criteria to access the EOD Series 60 publications.

Recording/Tracking. For incident recording and tracking purposes, the system prompts the user for pertinent

information. It also tracks the status of the incident.

Identifying Objects. The AI-EOD system's unique search and retrieval capabilities assist the user in identifying objects. For example, the search can be by characteristics, such as physical attributes, by common name or alias, by nomenclature, or by publication number.

Audit Trail. During a session, each characteristic, or lack of a characteristic, is recorded as the user enters it. This record serves as a type of audit trail to document the activities of the user.

Listing. Based on information the user provides, the system displays and updates a list of relevant publications in real time. The system also evaluates and rates the publications with the best "fit" at the top of the list.

Viewing. At any time, the user can select for viewing one or more publications, consisting of text and images, to assist in confirming the identity of an object. Viewing features include multiple windows, zoom-in/out, rotate, and scroll.

Reporting. When a hard copy of the publications would be useful, the user can select one or more publications for printing on a laser quality printer. The audit trail notes can also printed.

AI-EOD Features and Benefits

A number of special benefits and features associated with the AI-EOD prototype are summarized in Figure 1.

UNIX/XWindows	•Consistent, intuitive graphical user interface (GUI)	•Can conduct parallel searches accessing the same documents or different documents	•Portable
	•Short learning curve		•Complies with DOD standards
Artificial Intelligence/ Neural Net	•Modeled after actual neurological processes	•Represents an innovative implementation of AI technology	•Combines phonetic and 'fuzzy' searches
	•Can reach conclusions based on incomplete or inaccurate as well as negative data	•Evaluates and rates the publications, and places the publicati- with the best 'fit' at the top of the list	•Displays and updates a list of relevant publications in real time
	•Suitable for other platforms (e.g., DOS/Windows) as well as other applications		
Image and Text	•Viewing features include multiple windows, zoom-in/out	•Select one or more publications for printing on a laser printer	•Records searches as a type of audit trail
Object-Oriented Programming	•Models reflect aspects of the real world	•Creates a more reliable, error-free system	•Shorter development time
	•Maintainable	•Flexible, adaptable	•Longer life span
	•Reusable	•Capable of evolving	

Figure 1. AI-EOD Prototype Features and Benefits

TEST AND EVALUATION

The test and evaluation (T&E) effort was conducted to collect and analyze information on the reliability and validity of the AI-EOD delivery system. Performance is measured by time and accuracy (AI-EOD vs. conventional). Demographic, and utility and usability information about AI-EOD was also collected.

AI-EOD Testing Episodes

For AI-EOD, performance is measured by how quickly and accurately an EOD technician can identify an ordnance shape and locate the RSP for the device. This process closely relates to the ordnance identification requirement

encountered in the operational environment.

AI-EOD testing begins by presenting the technician with a piece of unknown ordnance (a shape). The technician must identify the shape and determine the RSP using either the conventional or AI-EOD system. Completion is the reporting of the IG number (i.e., the Series 60 publication) and page number of the RSP.

Ordnance Shapes. Shapes provided for the identification episodes were selected utilizing the following criteria: (1) Selections must be made by expert EOD technicians; (2) shapes must represent realistic and cross-service ordnance identification requirements; (3) shapes could reasonably be identified but were not so familiar that the technicians would not be tested; and (4) shapes had to be easily transported from one test site to the next. A number of shapes were provided and, as a result of the verification, final test shapes were selected (Table 1).

Shape # RSP Pg.	Country/Nomenclature/Model	Publication	ID Guide Page	Inert Sticker
	SET I TEST SHAPES			
1/7,8	UK Bomb Unit, HEAT,Nol MK1	60B-3-2-11*	11-27	NAVEODFAC 2801
2/4	US Projectile, 40mm, HEDP, M430	60D-2-2-23-10	3-593	USMC 10751
3/5	USSR Projectile, 82mm, HEAT, BK-881M	60D-35-2-2	3-297	NEODTC 0557
4/6	French Landmine,APERS,Nonmetalic,1951	60H-7-2-6	6-37	301987 Inscribed
	SET II TEST SHAPES			
5/6	Italian Landmine, APERS, AUPS-BRIND	60H-9-2-16	6-66	NAVSCOEOD 601095
6/8	USSR Rocket, 64mm, HEAT, PG-18	60F-35-2-27	3-142.1	NEODTC 0967
7/3	Czech. Projectile Fuze, PD, MZ 36	60D-20-3-10	3-1167.2	USMC 15366
8/5	French Grenade,Rifle,HEAT,65mm,M1961	60E-7-2-3-13	3-141	NAVEODSCL 301804
	PRACTICE/TRAINING SHAPES			
P1/14	US Bomb, HEAT/FRAG, MK 118 Mod 0	60T-2-2-6	11-14	NEODTC 0650
P2/8	US Bomb Unit, Training, BLU-26-(T1)/B	60T-2-2-11*	11-22	Produced Inert
P3/5	Italian Landmine, APERS, VS 50AR	60H-9-2-11*	6-54	Rubber Trng Aid

* = Multiple Ordnance Publication.

Table 1. AI-EOD Practice and Test Shapes

Identification Evaluation Measures. T&E episodes focused on the identification process. The measures were speed (time) and accuracy (number of errors) in identifying the ordnance device and RSP.

Method

Research Hypotheses. Hypotheses for AI-EOD T&E are divided into six categories: (1) EOD performance (as defined by completion time and errors made during test episodes), (2) EOD knowledge (as defined by training time), (3) EOD experience/ability (as defined by years of EOD experience, paygrade, time in service, personal assessment of EOD skills, and whether currently working in EOD), (4) AI-EOD utility/usability of the AI-EOD (measured by responses on utility questions), (5) computer experience/qualification (measured by personal responses), and (6) general factors (age, time in pay grade, gender).

Test Administration Procedure. NPRDC personnel administered the test in an office environment at the various operational sites. The conventional test was completed using the technical documentation normally used by EOD technicians. The AI-EOD test was accomplished using the prototype AI-EOD delivery system.

The subjects were given an instruction and information sheet to read and a background questionnaire to complete. Next, they watched a 1-hour demonstration of AI-EOD system and received instruction in its use. The subjects were then assigned to one of eight test sequences to protect the AI-EOD test and evaluation study from test order effects. Each subject was administered three practice and eight test episodes.

Each testing sequence took approximately 2 hours to complete, although there was no specific time limit. The subjects completed the first four episodes in the test sequence using one of the delivery systems and then used the alternate system for the other four episodes. The administrator was present throughout the testing sequence to issue the shapes and to record performance data.

Subjects. The AI-EOD system was designed to be utilized by every level of EOD personnel in all EOD environments. The delivery system was verified and validated, and the test and evaluation procedures were modified accordingly by expert EOD technicians assigned to the NEODTC.

The system was then used to gather baseline performance data from the expert (instructor) and novice (student) personnel at the EOD school. The research subjects were members of all four services at three skill levels (as normally defined by experience and paygrade): novices (school students and EOD assistants), journeymen (experienced on-the-job EOD technicians), and masters/experts (personnel who had extensive experience or met special qualifying

requirements through assignment as technical experts, such as instructors or technical positions, or were "master blasters").

Data Collection. NPRDC collected data for the master data base for 242 subjects at 24 sites between March and August 1991. The data base contained demographic data from the initial questionnaire, performance data for each completed testing sequence, and critique data collected from each subject after testing. Data were entered into a computerized statistical package, and descriptive statistics were computed.

After the data were checked for completeness, a preliminary evaluation was performed to inspect the data for various anomalies. Based on this evaluation data for 7 subjects were dropped due to missing data. Thus, the final data base contained data from 235 subjects. The resultant data base was used to create files to determine demographic results and for testing of the study hypotheses.

Results

Demographic Data. Demographic data for 235--10 instructors and 11 students at the Navy EOD school, and 214 operational EOD personnel--were analyzed and are presented in Table 2 .

The results for the ALL group in Table 2 might be summarized as follows: The 235 EOD technicians tested had an average age of 29 1/2 years; 97% were male and 3% were female; had over 9 1/2 years in service (9.6); and an average paygrade of E-6 (5.8) with over 2 years (2.2) in paygrade. They had received almost a year (11.2 months) of training in their EOD specialty; had been qualified as EOD technicians for almost 5 years (4.9); and had been working as EOD technicians for over 4 1/2 years (4.6). Almost 89% (88.5) of the 235 subjects reported that they were currently working as EOD technicians.

VARIABLE NUMBER AND TITLE (selected variables)	ALL	TEST GROUP Air Force	Army	Marine Corps	Navy
		(average responses)			
1. Age (in years)	29.5	27.7	28.9	29.9	30.9
2. Gender (%age of males)	97.0	93.3	94.4	100.0	98.9
3. Branch of service (numbers)	235	60	36	52	87
4. Time in service (in years)	9.6	7.6	8.5	10.2	11.0
5. Paygrade	E-5.8	4.7	6.1	5.9	6.3
6. Time in paygrade (years)	2.2	2.2	1.7	2.2	2.5
7. Amount of EOD training (months)	11.2	9.0	10.8	7.6	15.0
8. Time qualified as EOD tech (years)	4.9	6.1	4.9	4.3	4.4
9. Time working as EOD tech (years)	4.6	5.7	4.8	4.3	3.9
10.Currently working-EOD tech (yes)	88.5%	93.3	100.0	96.2	75.9
11.Self evaluation-EOD expertise	4.7	5.2	5.3	4.5	4.4
		(for variable 11 0=none -- 9=expert)			
12.Self evaluation-computer experience	3.1	3.5	3.1	2.7	3.1
		(for variable 12 0=none -- 9=expert)			
25.Average time- AI-EOD (min.)	5.0	4.9	4.7	4.6	5.9
26.Average error rate- AI-EOD	.04 (1%)	.03 (.75%)	.03 (.75%)	.06 (1.5%)	.04 (1%)
27.Average found- AI-EOD	4.0 (100%)	4.0	4.0	4.0	4.0
40.Average time-conventional (min.)	9.6	8.8	7.8	9.5	10.9
41.Average error rate-conventional	.46 (11.5%)	.60 (15%)	.42 (10.5%)	.33 (8.25%)	.46 (9.25%)
42.Average found-conventional	3.93 (98%)	3.92	3.92	3.92	3.97
	(for variables 59-66 1=strongly agree -- through -- 9=strongly disagree)				
59.I like the current system	5.9	6.0	5.6	5.1	6.5
60.I like the new AI-EOD system	1.9	1.7	2.1	2.1	1.9
61.I would rather have the current system than the AI-EOD	7.4	7.3	7.2	7.1	7.7
62.I would use the AI-EOD system rather than the current system	1.9	1.8	2.0	2.4	1.7
63.The AI-EOD was easy to use	1.9	1.8	1.9	2.3	1.8
64.The AI-EOD needs major modification to be useful	6.6	6.7	6.7	6.5	6.7
65.I am fully qualified in EOD	3.4	2.8	2.9	3.3	4.1
66.I am fully qualified in computers	5.7	5.5	5.3	5.9	5.9

TABLE 2. Demographic Results: Selected variables

In terms of their expertise or knowledge, the subjects considered that they had from some-to-much expertise in EOD and they reported little-to-some knowledge and experience with computers.

The results of the testing on the eight test episodes (four AI-EOD, four conventional) show that:

Using the AI-EOD system the subjects took an average of 5 minutes to identify the unknown shape and determine the RSP for the four test episodes, with .04 identification errors per test exercise, which is an error rate of 1%;

they correctly identified all four shapes of the test (100% solution rate).

Using the conventional approach (i.e., documents and microfiche), the subjects took an average of over 9 1 2 minutes (9.6) to identify the shape and determine its RSP, with and average of .46 errors per test sequence, which is an error rate of 11.5%; they correctly identified 3.92 of the 4 test shapes (98% solution rate).

When asked for their opinions upon completion of the testing sequence the subjects reported that they did not care for the current (conventional) system; they liked the AI-EOD system very much and, if given a choice they would rather use AI-EOD rather than the current system; and, if both systems were available, they would use the AI-EOD system. They considered the AI-EOD system easy to use and in need of no major modifications to be useful. In a second query about their EOD and computer qualifications, they considered themselves qualified in the area of EOD and they moderately disagreed that they were qualified in the use of computers. The results for each service could be reported in a similar fashion as was done for the entire population (ALL).

Hypotheses. Results of hypotheses testing are presented below.

1. EOD Performance.

Subjects will complete test exercises significantly faster using AI-EOD than using conventional (AI-EOD time vs. conventional time)

Subjects will have significantly fewer errors with AI-EOD than with conventional (AI-EOD errors vs. conventional errors).

Subjects will have a significantly higher identification rate using AI-EOD than when using conventional (AI-EOD identification rate vs. conventional identification rate).

Results. Table 3 shows that average completion time was significantly shorter using the AI-EOD system than the conventional approach; errors were significantly less using the AI-EOD system; and performance significantly improved, in terms of problems solved, when using the AI-EOD system.

Discussion. The general and significant increase in all EOD performance measures when using the AI-EOD system compared to conventional leads to the conclusion that the AI-EOD prototype improved EOD technician performance. This indicates its validity from a job-performance-aid (JPA) perspective. The fact that the results were consistent across all the performance measures and all subjects/services provides a practical statement regarding

Factor	Computer	Conventional	Number	F Ratio	Probability
	PERFORMANCE COMPARISONS				
Average Time of Completion (in minutes)	5.043	9.594	235	232.692	1.800E-13*
Average Error Rate (number/test set)	.038	.460	235	53.912	8.800E-13*
Average Number Found (per test set)	4.000	3.936	235	6.992	8.462E-03*
	PREFERENCE COMPARISONS				
Average Response to "I Like"	1.902**	5.898**	235	613.836	4.000E-13*
Average Response to "I Would Use"	1.949**	7.387**	235	1020.830	7.000E-14*

*p < .05.

**Responses range from 1=Strongly Agree to 9=Strongly Disagree.

TABLE 3. Comparison of Performance and Preference: AI-EOD & Conventional Systems

the reliability of this JPA. The best approach for utilizing this new neural-net-based tool needs to be investigated further. This new tool will cause major modifications in the way we approach performance of a number of the EOD tasks. The change in how the EOD technicians do their job and the introduction of computers into the workplace will also have major impact on manpower, personnel, and training decisions.

2. EOD Training.

Subjects with more EOD training will perform better, as measured by AI-EOD time, AI-EOD errors, AI-EOD identification rate, conventional time, conventional errors, and conventional identification rate (training time vs. performance).

Results. Table 4 shows no between the level of training and the factors defining performance.

Discussion. The lack of relationship between the level of training and the factors defining performance is somewhat surprising. This leads to a number of conclusions that are not inviting from a practical standpoint: for example, training is not relevant to on-the-job performance or vice versa, the task being accomplished is not a true representation of what an EOD technician must learn and do; or the task being accomplished is being driven by the tools provided.

The most supportable of these conclusion is that the approach of the conventional system is so restrictive that the EOD technicians cannot use the technical information learned at school. The EOD school provides information

about ordnance characteristics and how to identify and deal with each type of ordnance with these characteristics. However, the conventional identification procedures restrict the EOD technicians to only two characteristics in the initial identification process, major body diameter and overall length. They select a category of ordnance, thumb through a series of pictures until they identify the device using the diameter and length. If the device is not in the first category, they select another and continue thumbing through pictures until they identify the device. This limits technicians to performing three basic tasks, only one of which is moderately difficult; that is, measuring diameter, measuring length, and selecting category of ordnance.

	Performance Categories					
	AI-EOD		Conventional			
FACTOR	TIME	ERRORS	TIME	ERRORS	FOUND	N
EOD Training	-.02108	-.02933	.09454	-.08385	.03100	235
Time in Service	.05379	.02922	.18244*	-.12623*	.07868	235
Time EOD Qualified	-.08186	.06231	.03561	-.17106*	.05362	235
Time as EOD Tech	-.07804	.05747	.02910	-.14756*	.04384	235
EOD Experience	-.11296*	.02674	-.07629	-.19531*	.01034	235
EOD Qualification	.12820*	-.04092	.13730*	.22369*	-.11071*	235
Computer Experience	-.08567	-.00235	-.14465*	-.16388*	-.01319	235
Computer Qualification	.15243*	-.00358	.09049	.18588*	.10214	235
Age	.07967	.06158	.21366*	-.19861*	.06719	235
Gender	-.01901	.03497	-.00869	-.08134	-.03029	235
Paygrade	.09592	.07578	.10506	-.10831*	.05946	235
Time in Paygrade	.00079	.09782	.10473	.04334	-.02905	235
Currently Working	-.21611*	.00237	-.19320*	-.14944*	.04613	235

*$p<.05$

Table 4. Correlation Matrix for AI-EOD: Hypotheses Factors vs. Performance

AI-EOD allows for more ordnance knowledge as technicians answer the questions about the unknown device. Training does not correlate with AI-EOD because of the nature and design of the system, the neural net will accept a number of erroneous inputs and still assist the technician in correct identification of the device. The apparent lack of relationship of knowledge (training) to job performance should be investigated to ensure that the cause is not one of relevance, and to ensure the AI-EOD system is valid and reliable as a JPA.

3. EOD Experience/Ability.

Subjects who have higher experience/ability as measured by time in service, time EOD qualified, time working as EOD technician, EOD experience (self-report), and EOD qualification (self-report) will perform significantly better as measured by AI-EOD time, AI-EOD errors, AI-EOD identification rate, conventional time, conventional errors, and conventional identification rate (EOD experience/ability vs. performance).

<u>Results</u>. Table 4 shows no general relationship between performance factors and experience when using the AI-EOD system (except for the two factors of self-reported EOD experience and qualification, and time). There was, however, a of general and consistent relationship between performance and experience/ability (particularly with the performance factor of "number of errors") when using the conventional approach.

<u>Discussion</u>. This unexpected result could very well be associated with the task accomplishment restriction encountered with the EOD training hypothesis; that is, the conventional system does not allow for special performance as a result of greater ability and/or experience and the AI-EOD system tends to support users with lesser skills and abilities. Consequently, the relationship is weak, at best, between performance and experience/ability. This lack of relationship should be investigated to ensure that the cause is not one of training relevance, and to ensure the AI-EOD system is valid and reliable as a JPA.

4. AI-EOD Utility/Usability.

A significantly larger number of subjects will prefer the AI-EOD delivery system to the conventional approach as measured by their responses to the following critique questions:

a. I like the current microfiche system for identifying ordnance.

b. I like the new AI-EOD computer system for identifying ordnance.

Responses ranged from 1=strongly agree to 9=strongly disagree ("Like" conventional vs. "Like" AI-EOD).

Two other critique questions of preference were asked:

c. Given the choice, I would rather have the microfiche system than the AI-EOD system.

d. If both systems were available, I would use the AI-EOD system rather than microfiche.

Responses ranged from 1=strongly agree to 9 strongly disagree ("Use" conventional vs. "Use" AI-EOD).

<u>Results</u>. Table 3 shows a general and consistently significant preference for using the AI-EOD system as

compared to using the conventional system.

<u>Discussion</u>. The responses to the two preference questions revealed a very strong and consistent preference for the AI-EOD system over the conventional system. Inspection of the open-ended questionnaire and results of comments by subjects leaves little doubt that the subjects strongly preferred the AI-EOD system. It also appears that the computer literacy and acceptance of computers by the average EOD technician are significantly greater than the anecdotal inputs provided at the start of the project. The high level of user acceptance and preference clearly indicates that the EOD operational and training communities would welcome the computerized approach. Implementation of the AI-EOD system with its artificial intelligence component should be accelerated.

5. Computer Experience/Qualification.

There will be no significant relationship between computer experience or qualification, self-reported on computer knowledge/experience (using a scale from 0=none to 9=expert) and "I consider myself fully qualified in the use of computer" (responses ranged from 1=strongly agree to 9=strongly disagree), and performance results as measured by AI-EOD time, AI-EOD errors, AI-EOD identification rate, conventional time, conventional errors, and conventional identification rate (computer experience/qualification vs. performance).

<u>Results</u>. Table 4 shows no general and consistent relationship between computer experience and performance, except for a minor relationship to the conventional system.

<u>Discussion</u>. Computer literacy, use, and acceptance by the EOD technicians who took part in this study were significantly greater than expected at the start of the project. The lack of significant relationship between reported computer capabilities and performance confirms that computer expertise is not necessary to utilize the AI-EOD delivery system. Further investigation is needed to ensure that the results of the computer vs. performance results and conclusions are valid; that is, the construct of the user interface of the AI-EOD system can accommodate personnel with little or no computer background.

6. General Factors.

There will be no significant relationship between general factors, as measured by responses to questions addressing age, gender, branch of service, and paygrade, and performance results as measured by AI-EOD time, AI-EOD errors, AI-EOD identification rate, conventional time, conventional errors, and conventional identification rate (general factors vs. performance).

<u>Results</u>. Table 4 shows no general and consistently significant relationship between the general factors and performance, using the AI-EOD or conventional system.

<u>Discussion</u>. The design of the AI-EOD delivery system interface and search techniques successfully accommodate the differences presented in each of the general factors. Further, the lack of any relationship between any of the general factors and performance measurements appears to further confirm the limiting aspects of the conventional identification system as was suggested by the training hypothesis. The conventional system does not permit any variation in approach resulting from differing abilities or general factors. The lack of relationship of the general factors and performance needs further investigation to ensure the validity and reliability of the AI-EOD JPA. This would further support or refute the accuracy of previous conclusions regarding AI-EOD.

GENERAL CONCLUSIONS

The AI-EOD delivery system proved to be a reliable, valid, and user friendly job performance aid that significantly improved the performance of EOD technicians at all skill levels and across all services. EOD technicians participating in the test and evaluation study wanted to have this new tool as soon as possible. As a result the AI-EOD system should be moved to the implementation phase.

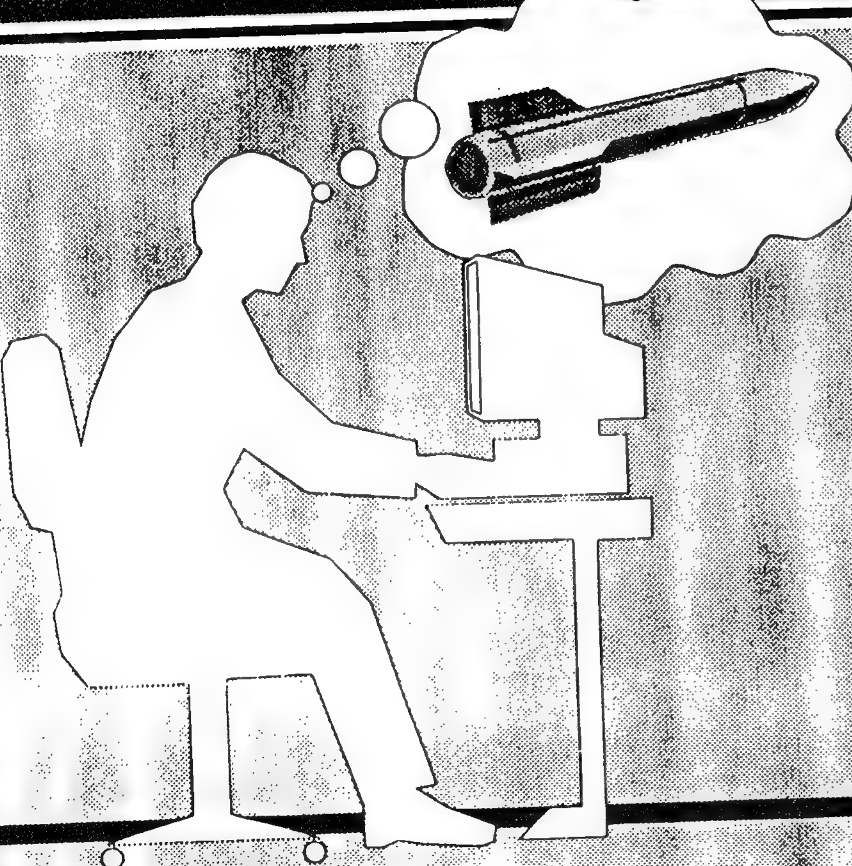
FUTURE EFFORTS

During implementation the AI-EOD system should be further tested, to confirm the validity and reliability of the approach. Also, the use of neural networks should be investigated for occupational fields (e.g., maintenance, intelligence, accounting, supply, tactics) and other data base types. This new type of tool (JPA) will require considerably more development, refinement, and investigation for optimum use.

REFERENCE

Conner, H.B., Madrid, R., Williams, R.A., & Holland, J. (1992, January). <u>Artificial Intelligence - Explosive Ordnance Disposal Information Search, Retrieval, and Delivery System</u> (in press). San Diego: Navy Personnel Research and Development Center.

AI-EOD



Artificial Intelligence Explosive Ordnance Disposal

ARTIFICIAL INTELLIGENCE-EXPLOSIVE ORDNANCE DISPOSAL

AI-EOD PROJECT MANAGEMENT

NAVY PERSONNEL RESEARCH AND DEVELOPMENT CENTER
SAN DIEGO
NPRDC

Navy Personnel Research and Development Center

Commanding Officer..........T. F. Finley Captain, USN
Project Manager..................................Dr. H. B. Conner

OVERVIEW

PURPOSE/GOALS:

TO DEVELOP AND EVALUATE FOR PROCUREMENT A COMPUTER-BASED TECHNICAL SEARCH INFORMATION AND RETRIEVAL SYSTEM TO:

- PROVIDE EOD FIELD UNITS WITH SEARCH TECHNIQUES, IDENTIFICATION AIDS, INFORMATION, IMAGING, AND COMMUNICATION CAPABILITY TO IMPROVE IDENTIFICATION SPEED AND ACCURACY, AND REDUCE CASUALTIES.
- AUTOMATE THE DISTRIBUTION OF TECHNICAL INFORMATION TO AND FROM EOD OPERATIONAL FORCES.

OVERVIEW

ANTICIPATED IMPROVEMENTS - QUANTITATIVE:

FIELD IDENTIFICATION AIDS:

- REDUCE THE TIME REQUIRED FOR CORRECT IDENTIFICATION BY 30%
- REDUCE THE NUMBER OF OPERATIONAL ERRORS IN ORDNANCE IDENTIFICATION BY 20%
- REDUCE THE NUMBER OF OPERATIONAL ERRORS IN THE SELECTION AND EXECUTION OF RENDER SAFE PROCEDURES BY 30%

OVERVIEW

ANTICIPATED IMPROVEMENTS - QUALITATIVE:

FIELD IDENTIFICATION AIDS:

- REDUCE LEVEL OF EXPERIENCE REQUIRED FOR COMPETENT PERFORMANCE
- REDUCE CASUALTIES
- INCREASE THE NUMBER OF EOD TECHNICIANS BY REDUCING REQUIREMENTS
- REDUCE CAREER AND SCHOOL ATTRITION
- ENHANCE GUARD/RESERVE EOD TECHNICAL SKILLS

OVERVIEW

PRODUCTS AND DELIVERABLES:

- **REQUIREMENTS ANALYSIS** - *SUMMARY OF COMMON AND MISSION SPECIFIC EOD INFORMATION REQUIREMENTS*
- **DATABASE TECHNOLOGY** - *TECHNOLOGY FOR CONVERTING EOD INFORMATION INTO AN INTEGRATED COMPUTER DATABASE*
- **TEST RESULTS** - *REPORT OF FIELD TEST RESULTS AND RECOMMENDATIONS*
- **ELECTRONIC DISTRIBUTION SYSTEM** - *SYSTEMS AND PROCEDURES FOR THE AUTOMATED UPDATING AND DISTRIBUTION OF EOD TECHNICAL INFORMATION*
- **PROCUREMENT SPECIFICATION** - *FUNCTIONAL SPECIFICATIONS FOR A PRODUCTION EOD INFORMATION SYSTEM*

AI-EOD OPERATIONAL SYSTEM AND SOFTWARE

- NEURAL NETWORK
- USER DEVELOPED INTERFACE
- UNIX OPERATING SYSTEM *(POSIX compliant)*
- APPLICATION SOFTWARE
  - *OPEN LOOK (WINDOWS)*
  - *C PROGRAMMING LANGUAGE*
  - *C++ PROGRAMMING LANGUAGE FOR NEURAL NETWORK*
- RASTER IMAGE DATABASE

AI-EOD HARDWARE

- **MONITOR** - *VGA, COLOR, INTENSITY & CONTRAST CONTROLS*
- **CPU** - *386 MINIMUM. 486 & MATH COPROCESSOR RECOMMENDED*
- **MAIN MEMORY** - *8 MEGABYTES MINIMUM. 16 MEGABYTES RECOMMENDED*
- **OPERATING SYSTEM** - *UNIX WITH X-WINDOWS or*
  DOS 5.0 WITH WINDOWS 3.1
- **APPLICATION SOFTWARE** - *EXPERT SYSTEM DATABASE*
  (VALUE/ATTRIBUTE PAIRS FROM EXPERTS)
- **HARD DISK DRIVE** - *400 MEGABYTE DISK MINIMUM*
  (100 MEGABYTES MORE THAN OPERATING SYSTEM)
- **CD-ROM PLAYER** - *STANDARD USING ISO 9660 FILE FORMAT*
- **IMAGE STORAGE** - *CCITT GROUP 4 RASTER IMAGE*
- **PRINTER** - *LASER WITH 300 dpi; 6 PAGES/MIN; 1 MEG PRINTER MEMORY*
- **GRAPHICAL USER INTERFACE (GUI)** - *OPEN LOOK (or similar)*
- **INPUT DEVICE** - *MOUSE, TRACKBALL, or JOYSTICK*

AI-EOD FEATURES & BENEFITS

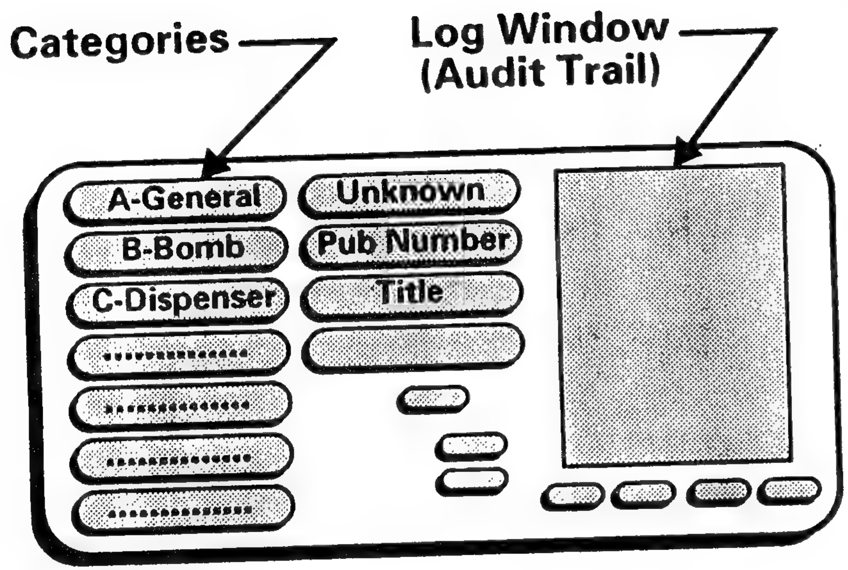
Unix/ XWindows	• Consistent, intuitive graphical interface (GUI) • Short learning curve	• Can conduct parallel searches accessing the same document or different documents	• Portable
Artificial Intelligence/ Neural Net	• Modeled after actual neurological processes • Can reach conclusions based on incomplete or inaccurate as well as negative data • Suitable for other platforms (e.g., DOS/Windows) as well as other applications	• Represents an innovative implementation of AI technology • Evaluates and rates the publications, and places the publications with the best "fit" at the top of the list	• Combines phonetic and "fuzzy" searches* • Displays and updates a list of relevant publications in real time
Image and Text Management	• Viewing features include multiple windows, zoom-in and-out, rotate, and scroll	• Select one or more publications for printing on a laser printer	• Records searches as a type of audit trail
Object-Oriented Programming	• Models reflect aspects of the real world • Maintainable • Reusable	• Creates a reliable, error-free system • Flexible, adaptable • Capable of evolving	• Shorter development time • Longer life span

**Fuzzy Search - An inexact search for data that finds answers that come close to the desired data. Fuzzy searches can get results when the exact spelling is not known, and they can help users obtain information that is loosely related to a topic.*

AI-EOD TEST & PRACTICE SHAPES

SHAPE No.	COUNTRY/NOMENCLATURE/MODEL
	SET I TEST SHAPES
1	UK Bomb Unit, HEAT, No. 1 MK1
2	US Projectile, 40mm, HEDP, M430
3	USSR Projectile, 82mm, HEAT, BK-881M
4	French Landmine, APERS, Nonmetallic, 1951
	SET II TEST SHAPES
5	Italian Landmine, APERS, AUPS-BRIND
6	USSR Rocket, 64mm, HEAT, PG-18
7	Czech. Projectile Fuze, PD, MZ 36
8	French Grenade, Rifle, HEAT, 65mm, M1961
	PRACTICE/TRAINING SHAPES
P1	US Bomb, HEAT/FRAG, MK 118 Mod 0)
P2	US Bomb Unit, Training, BLU-26-(T1)/B
P3	Italian Landmine, APERS, VS 50AR

AI-EXPLOSIVE ORDNANCE DISPOSAL SYSTEM (AI-EOD) BASIC SEARCH FUNCTIONS



GENERAL SEARCH INFORMATION

Four ways to search for a publication:

1. *By Category*
2. *Using the "Unknown Category" Button*
3. *By Title or Common Name*
4. *By Publication Number*

Dimensions are the most important identification features.
None of the questions <u>require</u> a response.
Fewer correct answers are better than trying to answer all questions.
Supply important or unique information <u>first.</u>

Search by Publication Category

Choose or guess the category of the ordnance.
Select items and respond to questions asked. (These questions relate directly to the chosen category. Note: If you decide to change the category, be sure to press the "Reset" button in the Main Window>)

Search When Category is Unknown

Select items and respond to questions asked. (These questions relate to all categories.)

Search Using Title, Common Name, or Alias

Input significant keywords; use acronyms where possible

Search by Publication Number

Input known publication number, or part of one.

DEMOGRAPHIC RESULTS

• EOD TECHNICIANS TESTED	235
• AVERAGE AGE	29.5 years
• GENDER	97.0% male
• BRANCH of SERVICE	
AIR FORCE	60
ARMY	36
MARINE CORPS	52
NAVY	87
• TIME in SERVICE	9.6 years
• PAYGRADE	E-5.8
• TIME in PAYGRADE	2.2 years
• AMOUNT of EOD TRAINING	11.2 months
• TIME QUALIFIED AS EOD TECH	4.9 years
• TIME WORKING AS EOD TECH	4.6 years
• CURRENTLY WORKING AS EOD TECH	88.5%

EOD TECHNICIANS PREFERENCE RESULTS

QUESTION	RESPONSE
I LIKE THE CURRENT SYSTEM	5.9*
I LIKE THE NEW AI-EOD SYSTEM	1.9
I WOULD RATHER HAVE THE CURRENT SYSTEM THAN THE AI-EOD	7.4
I WOULD USE THE AI-EOD SYSTEM RATHER THAN THE CURRENT SYSTEM	1.9
THE AI-EOD WAS EASY TO USE	1.9
THE AI-EOD NEEDS MAJOR MODIFICATION TO BE USEFUL	6.6

*1=Strongly Agree & 9=Strongly Disagree

PERFORMANCE RESULTS

- AIEOD AVERAGE TIME PER SHAPE — 5.0 min.
- AIEOD AVERAGE NUMBER of ERRORS — .04 per test set
- AIEOD AVERAGE NUMBER SHAPES FOUND — 4 (100%)
- CONVENTIONAL AVERAGE TIME PER SHAPE — 9.6 min.
- CONVENTIONAL AVERAGE NUMBER of ERRORS — .46 per test set
- CONVENTIONAL AVERAGE NUMBER of SHAPES FOUND — 3.93% (98%)

COMPARATIVE RESULTS

AIEOD/CONVENTIONAL

52% REDUCTION in IDENTIFICATION TIME

with

87% REDUCTION in ERROR RATE

with

100% SUCCESS RATE

HIGHLY REALISTIC MICROCOMPUTER-BASED TRAINERS AS AN ALTERNATIVE TO TRADITIONAL SIMULATION

Dr. Richard W. Davis
Dr. Anthony C. Phelan

Regency Systems, Inc.
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Paper presented at the Third Annual Airborne Weapons Technology Review and Training Exposition: San Diego, CA, January 16, 1992

ABSTRACT

This presentation surveys the benefits of microprocessor-based trainers. Micro-trainers, an emerging class of part task and whole task trainers, exhibit most of the benefits of more complex simulators, but at much lower cost. The new trainers exhibit improved flexibility and ILS characteristics. Using current and near-future computer technology, it is possible to build highly realistic look-alike/work alike devices to replace actual aircraft or weapon system hardware and software in training systems. A key feature of the new micro-based trainers that separates them from previous generations of part task trainers is the fidelity they achieve in emulating the man-machine interface of modern aircraft and weapon systems.

Costs. Of the several benefits to training discussed in the presentation, cost reduction is the principal advantage of micro-trainers over simulators. The authors examine the sources of costs in simulators and trainers built from actual equipment to gain insight into why they cost so much. The main source of traditional training simulator cost is shown to be from the increased use of computerized electronics--especially the avionics--in modern aircraft and weapon systems. The cost of displays and the user interface are shown to be modest. At the heart of the micro-based approach is the idea of using a computer to mimic a computer.

This observation about cost leads to a strong argument in favor of using the micro-based approach. As electronics in the systems grow more complex and more integrated, the general view is that these computerized electronics are harder and harder to emulate, so the cost of emulating the system would approach the cost of using the actual system electronics in many cases. This paper refutes the argument that emulating modern systems is more difficult than emulating older systems. Examples of micro-based trainers are introduced in the presentation to show that low cost "emulation" of the man-machine interface and "sub-systems" can be accomplished at moderate cost.

Realism and Training Fidelity. Even professional trainers succumb to the argument that using the actual aircraft hardware is important because, "there is no substitute for the real thing." In electronics displays, however, the *real thing* may be a CRT display. CRT's and keypad input devices at the man-machine interface lend themselves well to low cost emulation. The micro-based trainers are remarkably accurate replicas of the actual equipment--often good enough to fool the subject matter expert. In addition, the increased flexibility, feedback analysis, and control possible with programmable trainers provide training benefits not generally available in an actual hardware based trainer.

Case Examples. Four examples of advanced emulators are reviewed to illustrate the main points of the presentation. The examples range from small emulators used as part-task training aids, to large, integrated systems that perform at levels comparable to traditional simulators. The cases demonstrated are:

- A low cost cockpit Control/Display Unit (CDU) typical of modern glass cockpit avionic keyboard and display devices.
- A portable aircrew trainer (PAT) for the P3C Orion Tactical Coordinator (TACCO) position.
- An integrated multimedia trainer for the AN\UYQ-21 shipboard command and control console.
- A "Cockpit Autoflight Procedures Trainer" capable of emulating all of the flight deck displays of a modern transport aircraft.

Using these examples of current emulation technology, the presenters will support the following points in their presentation:

- Even complex systems can be emulated with extremely high degrees of realism.
- Selective use of critical parts of the real man-machine interface can greatly increase realism and user acceptance.
- Cost reductions of 75% are routinely achievable over actual aircraft systems.
- Unencumbered from actual aircraft support systems, the trainers offer increased portability and operational flexibility.
- Significant training benefits result because of increased control and interface to other training technologies such as multimedia systems.
- Support issues, including tracking changes to the actual system, are fully addressed with well-designed emulators.
- Low cost commercial software can be used to program and control these trainers.

The summary includes a brief discussion of the key points. In addition the authors have provided a set of notes for contracting officers and others involved in preparing solicitations.

BACKGROUND: A GROWING NEED FOR SMART EMULATION

Thirty years ago aircrew training got done using a combination of three basic approaches: For about $4,000 to $5,000 per hour of direct cost, the aircrew could operate the actual aircraft on a training mission. For about $300 to $1,000 per hour, the aircrew could operate a simulator. For under $100 per hour a variety of classroom or minimally functional mockups and part task trainers were available. These often included the so called "paper tiger" or primitive part task trainer.

Today the training need and the economics have changed radically. The cost of operations with the tactical systems have increased tremendously, as have the cost of the simulators. As an example of this trend, the Boeing Commercial Airplane Company recently purchased a cockpit simulator for its 747-400 long range commercial aircraft. The $18 Million cost of the simulator is about the same price as the cost of an actual 707 aircraft thirty years ago.

The combined effect of increased training need and increased simulator and operational aircraft cost has combined to increase the demand for simulator and aircraft time while making that time much more expensive.

At a recent symposium on emulation at the Naval Ordinance Station, Indian Head, a Navy spokesperson called for a re-definition of *emulation*. The classical usage, they pointed out, referred to the imitation of one computer system by another. But the applied usage for training and other related disciplines they defined as:

> **...a low cost device that replicates the essential functional and physical characteristics of its high-cost tactical counterpart in a non-tactical environment.**

Both concepts of emulation are important. The training-oriented definition applies to micro-trainers as the term is used in this paper. But the technology of the micro-trainer often involves using one computer to imitate another as the more traditional definition implies.

MICRO-TRAINERS: DEFINING THE NEW CLASS OF DEVICES

To address this growing need for training emulators that approach simulators in their ability to train, but at costs much below those of conventional cockpit or full system simulators, several important training projects have turned to a new class of device. This new class of system, dubbed here the *micro-trainer*, is demonstrating its ability to fill a broad spectrum of training needs include both traditional simulators and traditional part task trainers. The term *micro-trainer* is introduced here to emphasize the application of micro electronics in the trainer; a more general term that could be used equally well is *emulator*.

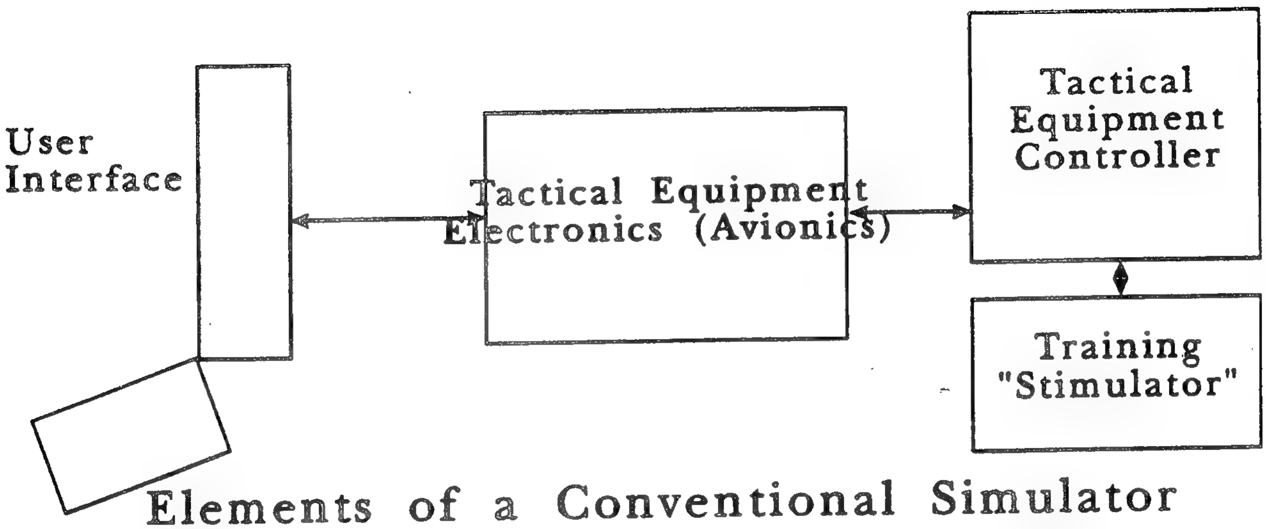
The essential characteristics of a micro-trainer include these items:

- The training device uses an internal microprocessor or micro-controller with an operating system for interface and control functions.
- The training device physically resembles or may precisely copy a piece of tactical equipment or an operational system.
- The training device performs some or all of the functions of the device it emulates as required by the training program.
- The device is software programmable, and may support some emulated functions separate from any other computer.
- The device contains standard communications interfaces, which permit it to be integrated into a larger trainer, or to be used as part of a CBT or other interactive instructional program.
- The trainer contains self-diagnostic and test routines to assist in maintenance and support.
- The device has a development environment or programming support environment for applications development.
- The unit MAY support the communications interface of the operational system, and could be used to replace the operational device in a simulator or training system.

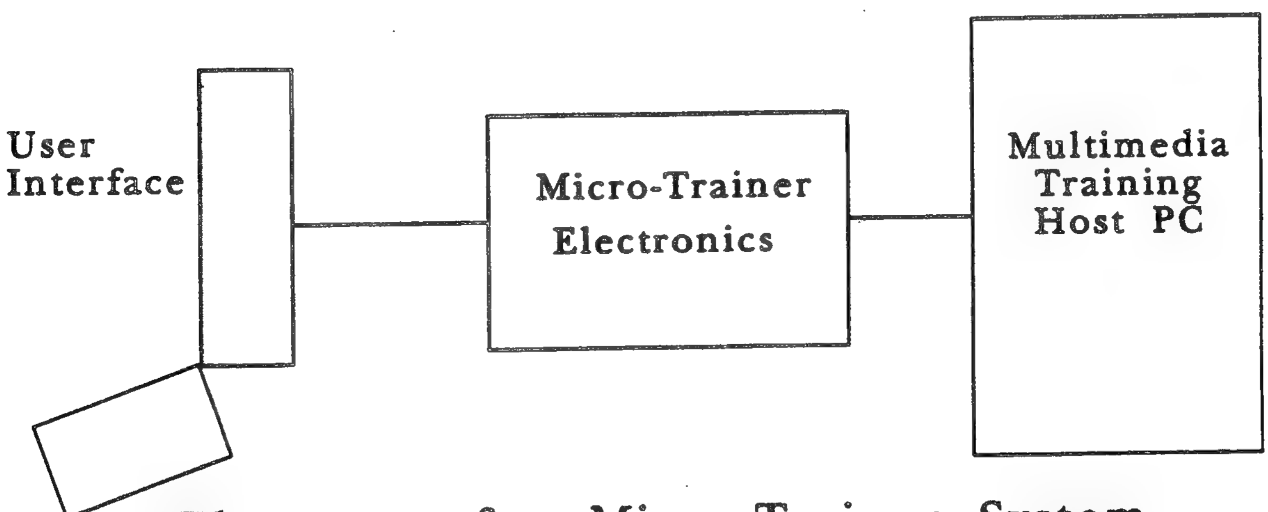
While these requirements may sound simple enough, devices that meet all of the requirements have been introduced only in the past few years. To dramatize the key differences, it is useful to compare a micro-trainer with an older part task trainer that used electronics. An example of an earlier generation part task trainer will help to highlight the differences. That earlier trainer, for a commercial transport, employed digital logic in the trainer. But following typical practice of five to ten years ago, the electrical connections for the lights and switches were individually routed back to a mini computer for control. In a micro trainer the control micro-processor would be built into the trainer itself, and only a serial or parallel control bus would connect the trainer to the computer. In the earlier trainer the electrical connections were all hard-wired to the computer. Not only do these hardware connections limit the flexibility and control of the trainer, but they cause an ILS headache as well. The hardwired connections prevent the trainer from being portable, since even if the trainer and computer can be moved, the cost and time required to disconnect and reconnect the wiring is prohibitive. Finally, there is no application development environment for the older trainer. The primitive computer I/O function means that a line of code was written to control each device, and that each simulated knob, light, or switch on the trainer was supported in a seaparate software routine. The older style trainer was supported entirely by custom written software written in assembly language or FORTRAN.

The micro-trainer represents advances on many fronts. In the micro-trainer, code is written in C or C++. While ADA support is available, ADA adds significantly to the cost. The presence of an internal commercial operating system in the trainer makes it possible to write code in a full featured, productive development environment, and even to simulate the performance of the trainer. This idea of a programmable trainer with extensive software control and a powerful external development environment is probably the biggest factor in the emergence of the micro-trainer as a distinct type of device. The

programmability is important because it permits precise control over the training device--indirectly contributing to increased realism and reduced cost.



Elements of a Conventional Simulator



Elements of a Micro-Trainer System

Figure 1. Comparison of Simulator and Micro-Trainer

The Micro-Trainer as Computer Peripheral: Improving Training

The argument put forward so far suggests that the principal benefits of the programmable training device are in lowered cost and increased realism--not specifically in imporoved training. But the micro-trainer does provide real improvements that the trainer can see and use.

One convenient way to start thinking about micro-trainers is to view them as specialized computer peripherals for training. Suppose that a training designer introduced a new peripheral into an interactive training system. That new peripheral looked like, and to a great extent behaved like, a part of the operational weapon system being trained. Examples abound, but to make the point, pick any keypad and display from a man-machine interface.

With such a peripheral, the training developers now have an impressive new capability. All of the task specific cues from the operational system are available; the trainers can now show the learner a highly realistic display, and give the learner a highly realistic response device in an interactive learning environment. In some cases, as in the examples discussed below, it will be possible to make this peripheral micro-trainer an exact replica of the operational system--indistinguishable from the real thing as it is used in training. The new feature, not available to trainers even a few years ago, is that the micro-trainer is fully under the control of the host multimedia computer. The training developer can precisely control what the micro-trainer displays to the learner, and can determine exactly what response the learner makes. The level of training control introduced by the micro-trainer is remarkable.

Realism is Important. The ability to get tremendous realism built into small, low cost trainers is a byproduct of modern electronics and avionics. As the units get smaller and more modular, it is actually easier to build look-alike/work-alike replicas of the man-machine interface. The knobs, buttons, lights, switches, and computer displays that show up in aircraft or on-board ship, are often commercially available. Even when they are customized for a particular weapons system, their appearance and function can be mimicked very precisely. Thus, even complex systems, like cockpits, can be emulated with extremely high degrees of realism. The programmability of the trainer helps the realism. The blink rate of lights can be precisely matched, even when different lights are used. The latency between a switch throw and a lamp illuminating can be controlled without the requirement of writing specialized code in the training material. The delay can be built into the micro-trainer control software. Even complex issues like the movements of meters, or the sounds of annunciators can be made more real because of the precise control available.

Selective Realism. Achieving high degrees of realism has become an increasingly important goal in training device design as trainers learn more about how sophisticated learners are in using the cues in their environment to perform at top level. But the need for realism is no longer an argument in itself for simulators, or using the actual equipment over building a "look-alike". That level of realism can now be achieved in much simpler training devices. There is a substitute for the real thing.

A hallmark of the trainers built at Regency Systems, Inc. is the selective use of critical parts from the real man-machine interface to greatly increase realism and user acceptance. As an example, in our cockpit trainers for commercial aircraft, all of the panel knobs are "actual aircraft" hardware with the same part numbers as those found in the manufacturer's parts lists. Many of the electrical switches and lights are also "real". But the avionics--the electronics modules--are emulated.

Often the decision to use the actual device or a lower cost alternative is made on a device by device basis with the customer. The trade-off is among these factors:

- The accuracy of the task cues provided to the student.
- The overall appearance and contribution to a feeling of "realism".
- The reliability of the device in the training application.
- The cost of the various approaches.

Realistic Displays. The most critical aspect of the micro-trainer in generating realism is the syswtem interface--the part of the trainer that the student touches and sees. Realistic emulation of the tactical system display requires special attention in both hardware and software. In some cases it is possible to obtain the tactical equipment display and integrate it into the micro trainer. This is especially true if the display consists of commercial projection switches or devices other than CRT's. To add realism to it trainers, Regency Systems has produced custom LCD displays and has used actual tactical switches to produce high-accuracy micro-trainers. There are many "tricks of the trade" involved in making low cost trainers look and feel like the real thing.

The greatest technical challenge to achieving realism is in CRT displays. Most cockpit displays in use today are calligraphic, or "STOKER" displays. This CRT technology is employed because of its high brightness, and because several generations of engineers have perfected the electronics needed to make stoker displays work in high performance aircraft under high G-forces, and at high altitude. But these devices are probably the most expensive part of the avionics system, and therefore are the first things to be critically examined in a cost reduced trainer.

Only recently have commercial computer electronics and graphics controllers gotten fast enough to closely approximate the look and performance of a stoker display. Even now, precise emulation of stoker displays is achieved only with a combination of outstanding graphics hardware, and specialized software to give the display the right look. Two of the examples discussed in this paper use raster emulation of stoker displays. One example is from cockpit avionics--the other is from a shipboard weapon system. Both efforts are good examples of selective realism, and both contribute significantly to cost reduction.

Cost Reduction. Several factors combine to give the micro-trainer a significant economic advantage over actual equipment-based trainers and simulators. Among these factors are:

- Commercial-off-the-shelf (COTS) electronics are used--MIL SPEC electronics are not needed.
- Electronic connections and functions not needed for training can be deleted.
- Productive, commercial software tools can be used to help lower development costs.
- Significant savings in hardware alone are possible by eliminating expensive connectors, fasteners, and mounts.
- The unit is not required to pass airworthiness or other tests required for airborne or ship-board tactical equipment.

While it is difficult to generalize about costs, Regency's experience so far is that the first article cost for a micro-trainer is less than the cost of an actual-equipment based trainer. Additional units offer significant reductions. The authors have seen several trainers built for approximately 25% of the cost of a trainer built from tactical equipment. One important commercial trainer effort produced a micro-trainer costing less than 10% what the actual aircraft equipment cost.

Portability. Unencumbered from actual aircraft support systems, the trainers offer increased portability and operational flexibility. Micro-electronics generally permit the electronics for a micro-trainer to be self contained--even for cockpit instruments and avionics modules. The example of the Regency MCDU for commercial transports is useful. The entire trainer including a high resolution graphics display, a keyboard, a hard disk, and a general purpose 16-bit processor is contained in a small box that is the same physical size as the actual aircraft device.

Since the micro-trainer is designed to work through standard interfaces, such as RS-232, SCSI, or MIL-STD-1553, the device can be used in a variety of environments, and can be made portable. In a typical application, the micro-trainer is teamed with a standard PC to provide interactive training environments with integrated, highly realistic part task training devices.

This portability is an important advantage if one is trying to overcome limitations of simulators. Simulators are literally tied down. Often an important part of reducing the training load on simulators is moving the training to the student and getting it away from the over-crowded simulator resource and its support environment. As training budgets tighten, portability will become increasingly important.

Interface to Other Training Systems. The significant training benefits resulting from increased control and the ability to interface to multimedia systems have already been introduced. The economic advantages of PC's and low-cost workstations in training are well understood. Returning for a moment to the idea of a micro-trainer as a computer peripheral, it is possible to see the enormous potential benefits of using the micro-trainer in tandem with a multimedia PC.

A practical training scenario that Regency's customers have employed, uses micro-trainer devices and a multimedia PC with an *option* strategy. The options include

interactive video, conventional CBT, or intelligent part-task trainer in a single system. In the training for a particular avionics system, the learners first see a brief video segment demonstrating a particular function. Then they work through a lesson on the PC with an animated graphic of the system's display shown on the PC screen. Animated graphics permit the use of arrows and highlights to direct the learner's attention to particular switches and display elements. But the learner can enter responses EITHER through the touch screen on the PC display, or on the micro-trainer connected to the PC. Finally, the learner is asked to perform a complete task using the micro-trainer. The host computer can monitor the student's work and determine if the instructional task has been mastered.

The combination of multimedia PC and the micro-trainer gives the training designer complete freedom to select the most appropriate presentation and response modes for the instruction. The hardware can support any training strategy from rigid, small frame lock-step programming to free play activity bordering on full simulation of the device. This advance is made possible by the use of simple, standard interfaces to the micro-trainer, its small size and portability, and the availability of a rich, productive programming environment.

Support and Dealing with Change. A common argument put forward in support of using actual tactical equipment in simulators and trainers, instead of using replicas or emulators as is recommended here, is that support of the micro-trainer is difficult. In particular, a major concern is tracking a change in the operational system. In a simulator built up from actual aircraft equipment, operational system field upgrades are tracked by making a change to the corresponding component in the aircraft. A good example is the updating of navigation data bases on aircraft. The data bases are updated in the simulator just as they are in the actual aircraft. Typically the simulator is assigned a tail number, so that the simulator gets any change that the particular aircraft sees.

It is true that the ability to track system modifications is extremely important. Since the life of a trainer may approach the life of the aircraft--10 to 15 years or more--this cost of changes can be higher than initial acquisition cost. The experience with micro-trainers so far, however, is that support for upgrade and maintenance in general is significantly helped. It is certainly greatly improved over earlier trainers where every change involved custom code and rewiring.

On new avionics displays, field upgrades typically involve modifications to the software in the avionics. A new display item, a change in color or appearance--these changes are typically very easy to implement in a micro-trainer, if the trainer software was done using a language like C, and if the development environment for the trainer was acquired along with the trainer. In other words, it is easy to make modifications if the change does not involve hardware change, and if the user owns the tools.

Large hardware upgrades involve extensive resources, but are typically less expensive to implement on the trainer than on the operational system. One issue planners need to be aware of is the lead time between the availability of the operational change

information, and the time the change can be made in the trainer. Coordination is required.

Perhaps the most difficult kind of modification is a small hardware change--for example, the change of a switch from a push button to a cover-protected toggle switch on an overhead panel. These mods may be more expensive on a micro-trainer than on an operational system. But overall, because the number of major system upgrades is comparatively small and the total cost savings in the micro-trainer are large, the micro-trainer will still show significant cost advantages over tactical equipment based trainers. Support issues, including tracking mods to the actual system, can be fully addressed with well-designed emulators operated in solid ILS programs.

ANALYSIS OF THE PRINCIPAL BENEFITS

The discussion so far has answered the "what is it" question. It has also included some discussion of how the micro-trainer is developed and used. From that discussion it is possible to get hints at its principal benefits to the training organization. Now it is useful to explore those benefits in detail.

CASE EXAMPLES: FOUR WORKING TRAINERS

Each of the trainers discussed below has been developed by Regency Systems and delivered to a customer. They vary widely in type of device, in the way the micro-trainer is implemented, and in how the unit is used in training. In the examples it is possible to see both the common elements that make all of these units "micro-trainers" as well as examples of the variety of application possible.

Multi-function Control/Display Unit: Cockpit CDU.

Background. In the "glass cockpit" the Multi-function Control/Display Unit (MCDU or CDU) is the equivalent of the computer terminal that the crew member uses to communicate with the flight computers in the aircraft. It is used for entering flight data, monitoring the flight computers, and in emergency procedures. It may also be used for maintenance functions. Its introduction into the cockpit caused major training problems for many commercial airlines. To some extent one could actually argue that this training need created the market for the modern "micro-trainer".

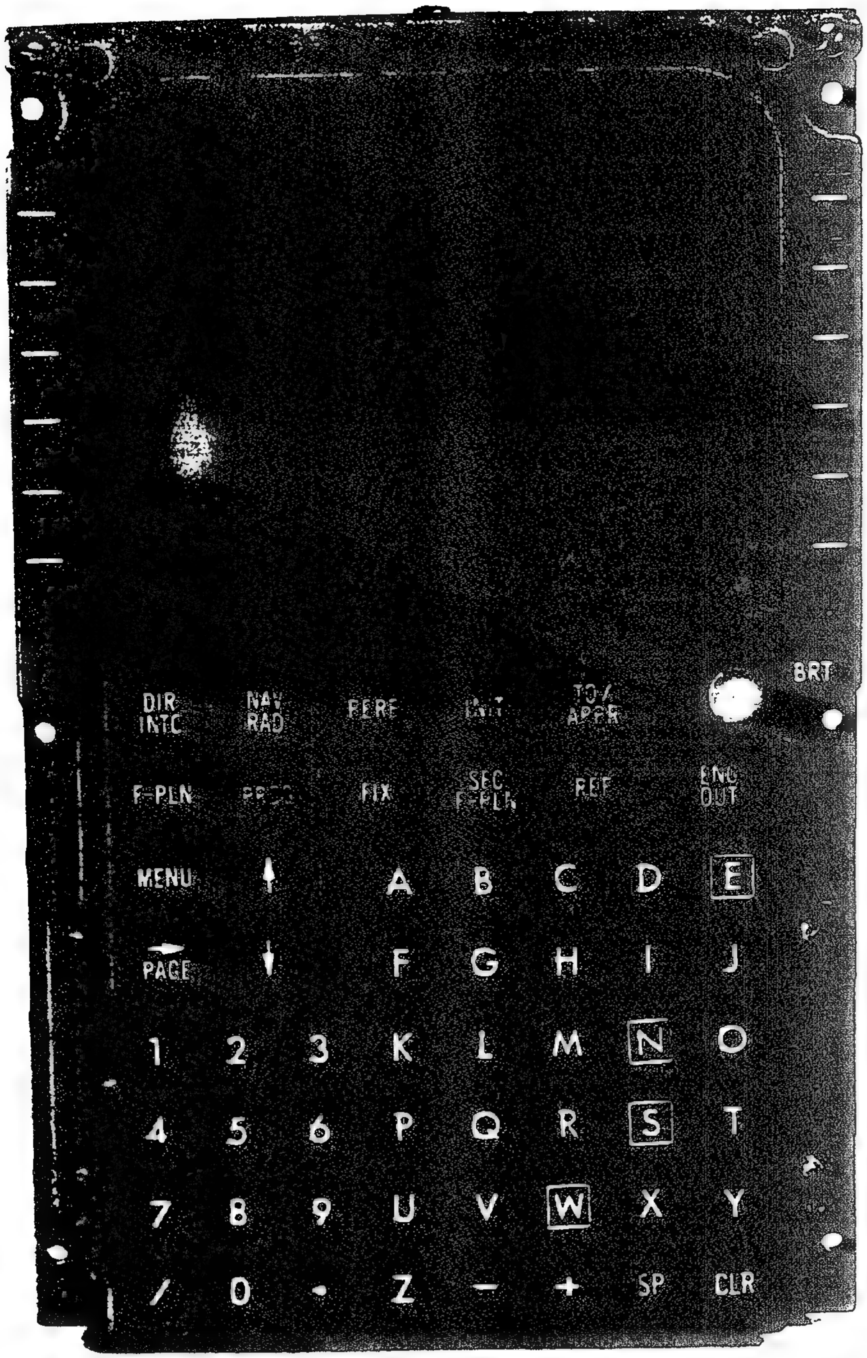


Figure 2. Regency Systems' Multifunction Control Display Unit for Contemporary Commercial Transport Aircraft

The MCDU Micro-Trainer. All of the key features discussed above are present in the MCDU trainer that Regency produces.

- It is self-contained and performs power-on tests and diagnostics
- It realistically emulates both the keyboard and display of the actual MCDU
- It communicates with a host processor
- It is supported with an extensive development environment
- It can be equipped with an ARINC-429 interface just like the one used on the actual aircraft equipment.

For a military aircraft, MIL-STD-1553 interfacing is available. Regency designed the MCDU micro-trainer to work either as part of a CBT system, or as a component in a cockpit procedures trainer.

The two major lessons from the MCDU experience are the importance of a high degree of realism and benefits derived from flexibility in the software communications and control interface.

Realism. The goal of the trainer's designers from the outset was to produce an extremely high degree of realism. The CDU is the primary control interface for the first officer in Navigation and Non-Normal Procedures. In addition, some airline customers expressed concern about "negative training", by which they mean poor training transfer, from primitive, unrealistic trainers. Regency's goal was to build a trainer that would fool not just the students, but the instructors and the subject matter experts as well.

To achieve realism, Regency took two tactics. First, we used several pieces of the actual front panel from the real MCDU were used in building the trainer. The key caps, the key switch mechanism, and the metal frame are the same as those used by at least one maker of the prototype device. The benefit is that the unit has the look and feel of the prototype.

The biggest challenge, however, was emulating the stoker display. Not only is the real unit a stoker device, but it uses a small, flat faced CRT with a sophisticated anti-glare coating typical of cockpit displays. After considerable searching, Regency was able to match the CRT tube itself, but not the electronics. So by using modified commercial parts, and with the help of some remarkably helpful vendors and some very clever technical staff work, Regency built a device that uses the right tube, but that operates like a conventional small computer monitor. In addition, Regency wrote a significant amount of software that generated a display on the screen that is identical to the appearance of the actual display. So in this case the design definitely traded away some cost advantage for an extremely high degree of realism.

Communications and Control. Airline customers requested that the MCDU trainer be useable in two quite different ways. First, they wanted to use it as an outboard peripheral in a CBT environment. But they also wanted to use it as part of a

cockpit procedures trainer. Beyond those two applications, Regency recognized that there might be a market for the unit as a stand-alone trainer with no outboard computer. Finally, planners thought that sometime in the future customers might want to support the actual aircraft ARINC-429 interface. The ARINC-429 data bus is to the commercial world what MIL-STD-1553 is to military avionics. The requirement that the unit work in a larger trainer meant that the device needed to fit the form-factor of the prototype MCDU.

To meet all these needs, Regency decided to build the trainer around a 16-bit general purpose computer (Intel 80286), rather than a micro-controller. The MCDU trainer has an internal bus, a full operating system, and an internal RAM-DISK. The communications interface is plugged into the bus, and can be changed out for various applications. The point is that the trainer is a complete computer in itself. If one wanted to run a spread sheet on it, you could. The opportunity to build the small, realistic device around a general purpose commercial computer has been made possible only in the past few years by the combination of low cost components and the availability of reduced size components and boards. As the lap tops and "palm top" computers continue to gain popularity, even more flexibility will be possible in micro-trainers that are, in fact, completely self-contained computers.

Generalizable Conclusions. The idea expressed here that realism and cost reduction get traded off is valid across a large number of applications. Using the real display, or producing a front panel that closely matches the actual device costs money. Building a unit that fits in the form factor of the actual device costs money.

The idea that the miniaturization of personal computers, and the continuing improvement in the price performance of commercial computers--especially PC's--strongly suggests that micro-trainers will become increasingly attractive in the future.

A Portable Aircrew Trainer

Background. The Tactical Coordinator (TACCO)is the P3 or S3 crew member responsible for utilization of sonobuoys and other resources to detect and track submarines. The position has a high skill level and requires practice to maintain proficiency. Using the aircraft and high fidelity weapon systems trainer to provide 100% of the required training and practice is expensive.

The Portable Aircrew Trainer (PAT). To provide training and practice in a lower cost environment, a Maryland firm, CRT Corporation, worked with the Navy over a 9 year period to develop a Portable Aircrew Trainer, or PAT. Their goal was to support all phases of training for the TACCO position in a portable device consisting of a self-contained PC for CBT, an outboard micro-trainer switch and display panel, and a complete courseware environment. Regency Systems worked with CRT Corporation on the development and manufacturing of the outboard micro-trainer.

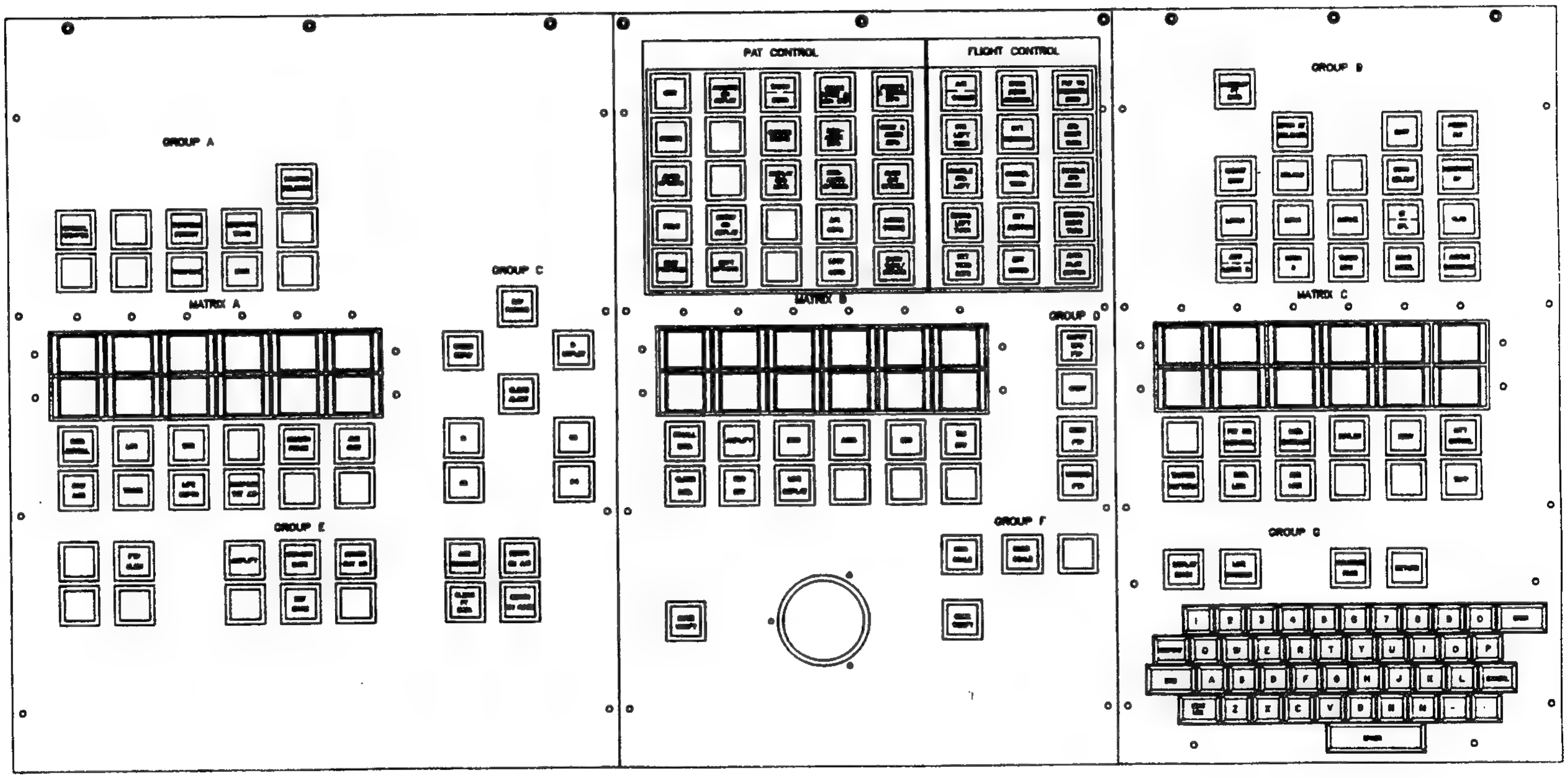


Figure 3. Plan drawing of Micro-Trainer Portion of CRT Corp's Portable Aircrew Trainer (Note: Three large rectangular switch banks are from tactical equipment.)

The main purpose of the outboard switch and display panel is to give accurate positional/procedural training with feedback. It is just one part of a fully integrated training environment.

Portability. A major goal of the PAT program was trainer portability. To meet the needs of the P3 squadrons, it was essential that the unit be small and self-contained. A prototype system built several years ago achieved these objectives, and has now led to acquisition of several additional production trainers. In Regency's efforts with the prototype, designers rediscovered the idea that portability requires increased ruggedness. If the unit is to be moved, the connectors, internal wiring, and the mounting of all components need extra strength. Even things like the paint need to be reconsidered in building a portable trainer.

Use of a Standard Micro-Controller. Key to Regency's strategy for making the portable trainer low cost was to use a standardized micro-controller. Early in its development program, Regency realized that if it had to create a new set of micro-controller electronics for each project, costs and lead times would be unacceptable. Regency created a standard unit, internally called the General Purpose Serial Controller (GPSC). This device consists of a family of COTS cards and backplane components, some developed and built at Regency, that can be configured to meet a broad variety of needs.

In the PAT micro-trainer, a three board GPSC unit provides the serial interface to the PAT's CBT host, and provides programmable control of the interface to the unit's large number of switches and indicators. The modular character of the GPSC make the internal layout of the micro-trainer much cleaner, smaller, and more reliable than we accomplished in the prototype. The modularity of design has been carried out to the software and the switch wiring as well, so that maintenance and CBT programming are greatly simplified.

Generalized Observations. Regency learned a valuable lesson about micro-trainers from our PAT experience--lessons that we have generalized to include all trainers. Modular electronics and modularity of design in general are powerful means for reducing costs and increasing reliability. Many of these modules meet requirements for COTS acquisitions.

AN/UYQ-21 (SQQ-89) Trainer

Background. With the development of the Aegis and the SQQ-89 sonar weapon systems, training planners in several Navy centers began to realize that continued dependence on tactical equipment for training was no longer practical. The high cost of tactical units (a real AN/UYQ-21 console costs over $400,000), plus the cost of driving those systems with computers from other parts of the weapon system, got many people thinking about emulation as an alternative. In addition, the rapid deployment of the systems meant that large numbers of people would need to be trained in a short period

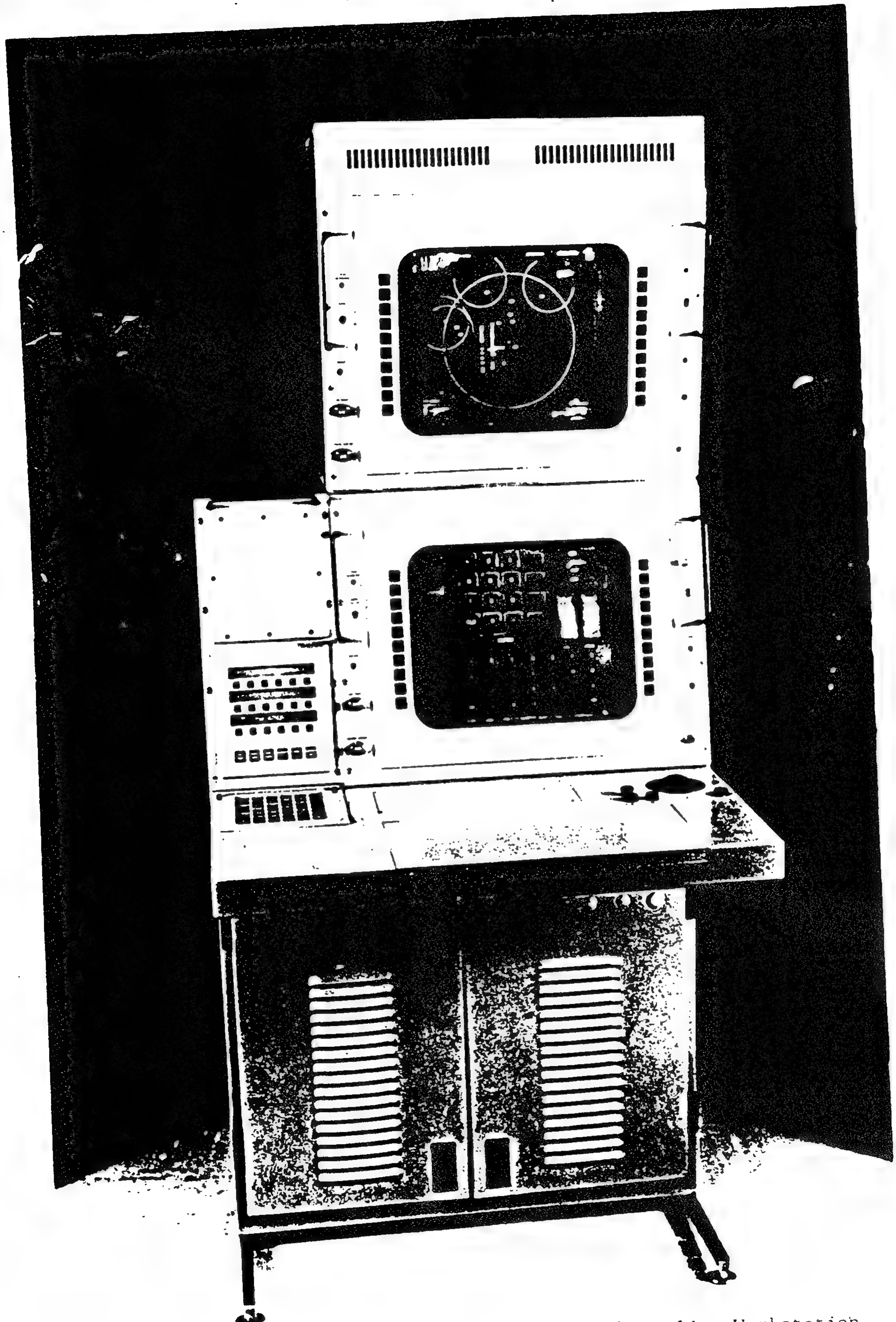


Figure 4. REgency Systems' AN/UYQ-21 (OJ-535) Replica Workstation
Upper display is Tactical GEOSIT display; Lower display is video.
Either display can show video or tactical graphics or CBT.

of time. So the number of systems needed for training became large. Several hundred training consoles are needed for SQQ-89 training alone.

As a part of a modular family of console displays, the OJ-452 and OJ-535 consoles used in the AN\UYQ-21 were natural candidates for emulation. Of particular appeal to one group of training designers was the idea that the OJ-535 console itself, with its large display monitors and trackball, could be a CBT training device itself. The same training device would be used to emulate the functions of the tactical equipment and to provide multimedia CBT instruction as well. Merging the micro-trainer and multimedia functions in a single unit is an innovative training concept.

The AN/UYQ-21 (OJ-535) Emulator. In 1989 Regency was awarded a contract to develop 12 prototype Interactive Videodisc Delivery Systems (IVDS). These workstations were complete multimedia systems with level III interactive videodisc, digital audio, high resolution color graphics, and a powerful general purpose PC. All of the components were housed in a console replica of the OJ-535 with the AN/UYQ-21 panels installed. These panels were fully active, so that the trainer could be used to emulate the functions of the AN/UYQ-21 as it is used in the SQQ-89 Sonar weapon system.

In 1991, the Naval Underwater Systems Center awarded a contract for the production version of the IVDS workstation components, also to Regency. This year (1992) NOS Indian Head is awarding a separate contract for the OJ-535 console replicas. When the workstation components are integrated into the console replicas, the resulting trainer is a powerful emulator as well as a full featured multimedia training system.

The principal motivation in turning to micro-trainer emulation for the OJ-535 was cost reduction. In the SQQ-89 program alone, cost savings in training from the use of emulation will exceed one hundred million dollars in acquisition costs over just three years. Savings over the program's 15 year life will be more than double that figure.

Note: Additional information about the IVDS project can be found in two papers to be presented in February at the SALT Interactive Instruction Delivery conference in Orlando. "Integrating Interactive Tutorials with High-Quality Equipment Simulations" by William J. Yalen of Analysis and Technology, Inc (North Stonington, CT), and "The Interactive Videodisc Delivery System: Advanced Training Technology for an Important Navy Program" by Richard Davis of Regency Systems, Inc (Champaign, IL) are both on the Orlando program.

Multimedia Integration. It is the multimedia integration of the IVDS that makes it unique as an emulator.

The multimedia characteristics of the IVDS workstation include almost all of the features of a contemporary multimedia PC environment. Among these are:

- Powerful CPU (33 MHZ Intel 80486)
- High resolution (1280 x 1024) graphics display

- Videodisc player
- Overlay of the video image, also at 1280 x 1024
- Digital audio record and playback
- Large capacity removable magnetic media
- Both Windows and X-Windows capability

. included in the initial plan is CD-ROM. The system does have a SCSI interface, so -ROM can be added at any time.

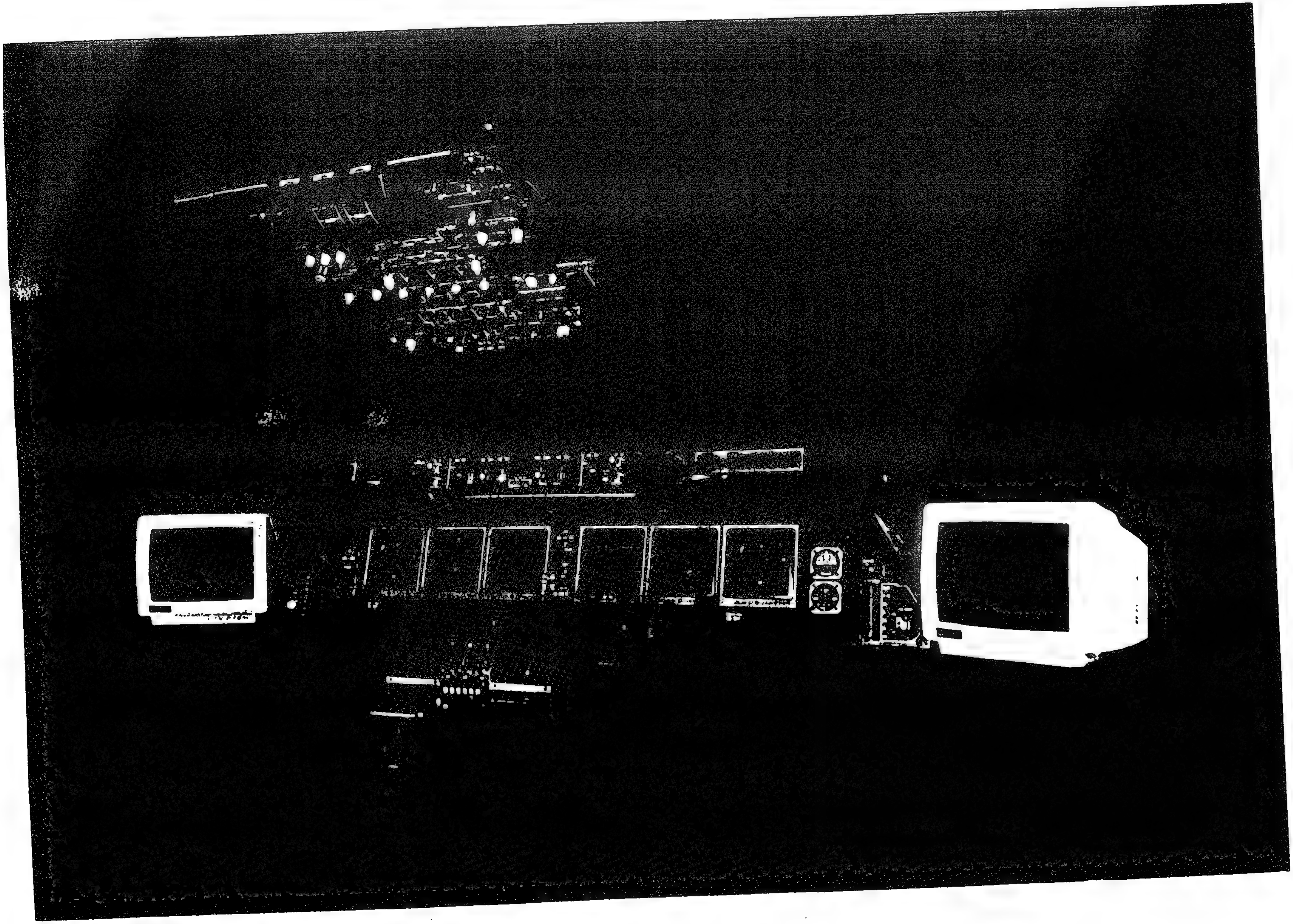
e prototype system and even the statement of work (SOW) for the production system re completed prior to the release of Windows 3.1 and the Multi-Media Extensions IME). Regency is working with the Navy to add MME support into the system-- pecially in audio.

he decision to build the IVDS system with both emulation and multimedia capability uilt into a single system was made only after extensive studies. An important bservation in those studies was that students had no difficulty in moving back and forth rom emulation to multimedia instruction on the same system. In fact it is not incommon to see both emulation and multimedia CBT going on together. The AN/UYQ-21 has two 21 inch monitors. Sometimes the trainers use one monitor to show a tactical display while running motion video on the other.

Use of Multiple Emulation Strategies in a Single System. An important point is that the IVDS system uses three entirely different strategies to achieve emulation. Using the same micro-trainer techniques discussed in the Portable Aircrew Trainer application above, the data entry panels of the OJ-535 are emulated on the trainer. Push-buttons and lamps are connected through micro-controllers to serial interfaces and then back to host processor. The trackball in the OJ-535, which is critical in terms of user control of the console, is the actual tactical equipment or a reduced cost commercial version of the same device. The trackball function of the trainer is real.

But the most dramatic feature of the console, and the most complex feature to emulate, is the CRT display. The tactical system the console supports calligraphic, monochrome displays. These units have extremely high performance. In the production IVDS trainer, two sophisticated graphics processors have been added to provide console display emulation while also supporting multimedia graphics. Each 21" color display is driven by a very high performance 32-bit graphics co-processor. Each processor has between 5 and 8 megabytes of RAM dedicated to it for the graphics function. An important point is that this graphics power was not available at reasonable cost until very recently. Even as recently as 5 years ago the graphics power needed to mimic the functionality of one OJ-535 display cost more than the whole IVDS workstation costs today.

Generalized Observation. The merger of the multimedia CBT function with emulator function into a single unit is a major step. While this approach is not unique to the IVDS program, the IVDS workstation is probably the most sophisticated existing example of this training direction.



Regency Systems, Inc.
MD-11 Cockpit Autoflight Procedure Trainer (CAPT)

CAPT: Cockpit Autoflight Procedures Trainer

Background. The introduction of the "glass cockpit" brought about a revolution in training as well as in avionics. The change in crew load, and the increased need for training time has created demand for training far in excess of what can be accommodated during aircraft or simulator time. To help off-load the simulators, commercial airlines and the military are turning to increased use of procedures trainers. For training in the "glass cockpit", the procedures trainer has become the most important device short of the simulator.

An important development in commercial aviation training has been the introduction by the FAA of a new classification system for flight training devices. Using the new seven tier system, full flight simulators are rated as "Level 6" devices, meaning they have sophisticated visual systems, multiple axis motion, flight controls with feedback, and instruments that give accurate representations of the aircraft instruments in real time. A Level 5 device has less sophisticated visuals, no motion, and less stringent requirements for controls and instruments.

The CAPT is a Level 4 device. It has no visual system and no flight controls, but for the devices it emulates, all functions of the aircraft are represented.

The MD-11 Autoflight Trainer. Regency has developed a cockpit procedures trainer for the McDonnell Douglas MD-11 aircraft. The CAPT focuses on the autoflight features of the MD-11's "glass cockpit" avionics. Included in the trainer are micro-trainers for the MCDU's, the MCP (flight or mode control panel), and the major flight instruments (primary flight display, nav display, and engine instruments/crew advisory system). In addition to the individual micro-trainers, the CAPT uses a main computer running under UNIX to emulate the flight control computers and flight management computers of the MD-11. The UNIX host also supports a flight model of the MD-11 so that the trainer behaves correctly in response to crew commands. All in all, the CAPT is equivalent in function to a conventional cockpit procedures trainer based on actual aircraft instruments.

Full Integration of Simulator Function using Multiple Micro-trainers. The Regency CAPT demonstrates a growing trend in trainers. The CAPT is a full cockpit simulator built up from a number of micro-trainers. All together, there are more than a dozen individual micro-trainers integrated into a single CAPT. One main computer is then responsible for the emulation and control of the entire trainer.

This technique works because of advancements on both the micro-trainer end and on the host processor end of the application. Each micro-trainer is itself a computer. So it can be developed, tested, and controlled independently of the other parts of the system. In the training system, each CAPT unit can communicate with other devices using low cost, standard connections, including not only serial channels, but local area networks and aircraft type communications interfaces as well. At the host end, the job of creating software has been made simpler by the steady advance of compilers and software development tools--especially for C and C++ languages. Whereas a conventional

trainer may represent a million lines of FORTRAN or ADA code, a micro-trainer based machine may require only 10% as much code written in C or C++. Furthermore, the code is highly modular and re-usable--an important consideration for maintenance and long term supportability.

Emulation of Complex Systems. The major lesson of the CAPT is that complex trainers can be built out of collections of simple micro-trainers. The CAPT itself can be looked at as a collection of 15 micro-trainers, plus a control computer. The open architecture of the trainer permits addition of new systems with minimum change. What emulation of complex systems requires, however, is a clear definition of functionality, together with a well-designed, well-managed software development effort. The number of functions, and the complexity of interactions among various parts of an aircraft or major weapon system make them difficult projects for emulation. To realize the cost reduction, portability, and training benefits of micro-trainers, projects need to be well thought out. Of particular importance is the generation of a requirements document that explicitly states what functions are emulated, and how the actual system behaves.

Generalized Observation. The two key observations to be made from the CAPT are that large systems work, even when they are complex, and that careful delineation of the functional requirements of the trainer are essential in large, complex emulations.

SUMMARY

The Expanding Role of Micro-Trainers. The key points set out in the abstract have been demonstrated. Micro-trainers provide effective emulation in a broad range of training applications--even complex systems such as cockpit simulators. Significant cost reductions are achievable. Continuing advances in micro-electronic and training technology promise further cost reduction and technical advances in micro-trainers. Increased budget pressures in training suggest that trainers will seek out the advantages of low cost, portability, and flexibility that micro-trainers provide.

Notes for Contracting and Procurement. The authors have reviewed over twenty solicitations--principally from the Navy and Air Force--for airborne and shipboard trainers that could involve micro-trainers. Based on experience in those solicitations, and in the author's work on the projects used as examples above, the following recommendations are offered to those writing solicitations that include micro-trainers.

- **Specify the precise functionality of the trainer in the solicitation, or include a CLIN (Contract Line Item Number) and DID (Data Item Description) for a requirements document to be generated by the vendor.** It is essential that there be absolute clarity about what functions the emulator is to emulate. Without such clarity conflicts are almost certain to arise about what the unit is supposed to do. It is reasonable for 10% of the project NRE to go into the requirements document; it will save money in the long run. It is not sufficient, by the way, to simply state that the training device will have the same functionality as the tactical equipment.

- **The solicitation should include a CLIN for the development environment of the trainer software.** Solicitations typically require the vendor to provide documented code and even, in some cases, to provide source code. But unless the development environment for that code is also purchased, the trainer's code may be difficult or impossible for the customer to maintain. So not only is it important to acquire the code; it is essential to acquire the tools used to create the code.

- **Acquisition of source code may not be possible in all cases.** It is probably unrealistic to require that ALL source code be provided. In the first case, the vendor may not have rights to some of the source code--especially if it is commercial software. But even if the source code belongs to the vendor, its development cost may be very high. Two negative results may occur. Some qualified vendors will not respond to such bids because they refuse to give up their rights. Or, if they do bid, they may price themselves out of the competition on the source license CLIN's alone. Source code should be an option, and probably should be considered separately in cost evaluations.

- **Preconceived notions about the technology used in the micro-trainer will raise costs and reduce effectiveness.** Micro-technology is advancing so rapidly that any unnecessary constraints put in a solicitation will almost certainly drive up costs and limit the ability of the vendor to use their best efforts. As an example, a recent solicitation required four processors in a particular micro-trainer. Some bidders had access to technology that permitted superior performance to be achieved with only one processor. The effect of the technology requirement was to raise the bids by over 5% and to cause vendors to use less effective technology. A better approach would to have been to state that four processors were known to work, and to ask the bidder to describe the micro-trainer architecture in detail in their technical response.

- **Clearly establish requirements for the quality of the replica.** This point gets at two different but equally important issues. The people writing the solicitation are typically very familiar with the tactical system; the people responding to the solicitation are generally not nearly so familiar. This means that the writers have a strong set of assumptions about what the replica will look like--about how faithful the emulation will be. Unless this requirement is communicated in the solicitation, the responders are likely to use a different set of expectations in planning the device.

The other problem is that cost and the quality of replication are related. So in a technically acceptable/lowest cost competition, the vendor is strongly motivated to sacrifice fidelity to save money. To make sure they get what they want, the authors of the solicitation need to be as clear as possible about what they want. Among the objective features that can be specified as requirements are: finish, materials, color, legends, switch action (stroke length, pressure, click), lamp color, lamp brightness, and dimensions.

- **Whenever possible, the contracting officer should make arrangements for bidders to get access to an actual unit and to full documentation of a tactical system.** It is almost universal experience among training device vendors that seeing the unit is even more valuable than the documentation. Seeing the prototype reduces risk for the training vendor. Clarification about how a particular switch works, or how a particular function operates can help the vendor identify the most cost effective way to build the micro-trainer. This reduced risk will translate directly into lower acquisition cost. The same is true post award. The government should furnish access to the prototype (within limits) as part of the information available to the successful bidder. Documentation of the prototype is essential in making sure that individual functions are correctly supported.

- **ADA should be avoided in favor of C or C++.** One key to the low cost of micro-trainers is the availability of commercial development tools for micro-controllers. The tools are part of the project cost. Since the corresponding tools in ADA are much more expensive, and not nearly as productive as the highly developed C tools, ADA is a weak choice for micro-trainers compared to C or C++. Since these micro-trainers are NOT tactical equipment, the argument for waiving ADA is strong.

- **Keep the micro-trainer in the training device category.** Procurement rules and organizational pressures often put the contracting officer in the position of wanting to purchase the device as data processing equipment or as audio-visual equipment. The danger here is that firms with no training experience will respond. Since they have no experience in building training devices, the customer will inherit the problems of the vendors first effort at a micro-trainer. Vendor qualification is important, both in terms of assurances of product quality, as well as in helping the vendor work effectively with the customer to meet the real training need.

- **Allow adequate time between "First Article" delivery and the first production shipment to accommodate changes.** There are almost certain to be revisions to the software, and there may be revisions to the hardware of the trainer following evaluation of the First Article shipment. It is important that there be enough time in the schedule to permit those changes to be integrated into the production systems. Allowing only 30 days between First Article and production is probably not adequate time to permit adequate technical review AND to put changes in place.

- **Real Time operating systems are generally not a significant advantage.** In the experience of the authors, "real time" operating systems in a trainer greatly increase its cost, but produce little or no *observable* benefit in the training. One reason for this is that computers today are so fast and so inexpensive that it is almost always easier and cheaper to add computer speed than it is to add real time operating system control.

- **Keep the vendor involved in the ILS program.** The vendor is in the best position to assist the user with maintenance, upgrades, and even training development. While it is common to purchase the micro-trainer under one vehicle, and training development under another, it is important that the vendor be able to provide specialized services after the micro-trainers are delivered. Viewing the micro-trainer acquisition as a single equipment acquisition ignores important program needs for integration and support.

"EMBRACING THE DEMONS OF TRAINING DEVICE ACCEPTANCE TESTING - THE PROCESS IMPROVEMENT LEGACY"

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ABSTRACT

Under the auspices of Total Quality Management, a small group of Government and industry specialists examined the existing training device acceptance test process for potential improvements. The agreed-to mission of this Air Force/Industry partnership was to identify and promote implementable approaches to minimize the cost and time required for acceptance testing while ensuring that validated performance supports the operational training requirements. Application of a process improvement model focused on the customers and their requirements, analyzed how work was accomplished, and led to the identification and elimination of several non-value added components in current test practices.

Diverse technical and management approaches were blended into a single improved process known as Simulator Test 2000 (ST 2000). ST 2000 integrates timely, accurate, streamlined test documentation, provides safeguards for increased confidence in contractor verification testing, and improves on-time test milestone performance via an optimum balance of government/contractor specification performance validation procedures. By testing at a functional level in lieu of detailed testing constructs, this customer oriented approach emphasizes operational checks to determine ability to satisfy training objectives and eliminates Government repetition of previously conducted contractor tests. ST 2000 methodologies have been melded into both new and ongoing Air Force training initiatives. Further improvement highlights are those for contractor test performance incentives and commercial-type warranties.

To significantly reduce the number of Government test requirements, the joint Air Force/Industry team has formulated a total of 27 complimentary recommendations surrounding the test process. These improvements are estimated to save in excess of 40 percent of Government test time without compromising test objectives. This paper describes the development of these training device acceptance test improvements and the status/results of their implementation.

INTRODUCTION

When late during the summer of 1989, President Bush selected John Betti for nomination as Under Secretary of Defense for Acquisition, Total Quality Management (TQM) was fast becoming more than a household word. In fact, TQM was on a course destined to become an intrinsic management philosophy within the Department of Defense (DoD). For purposes of this paper, consider TQM as a leadership philosophy that creates a working environment which promotes trust, teamwork, and the quest for continuous improvement. Other essential elements of TQM require dedication, conviction, and a willingness to bring about change, to do the right things right, the first time, with the ultimate goal being customer satisfaction.

At about the same time as Betti's nomination, the Training Systems System Program Office at Aeronautical Systems Division (ASD/YW), Wright-Patterson AFB, Ohio was plowing new and fertile ground with contractors from the training system industry. Chartered in August 1989, the YW/Industry Total Quality Steering Group developed a mission "...dedicated to continuous process improvement and the acquisition of training products and services to produce the best trained aircrews and maintenance personnel in the world". The primary thrust of this Government/industry forum was to identify and provide recommendations to improve high level cross organizational processes having a critical impact on satisfying the customer's requirement using the principles of TQM.

THE CRITICAL PROCESS TEAM. The first Critical Process Team (CPT) chartered by the Steering Committee was to investigate aircrew training device acceptance testing. The team was tasked to thoroughly study the acceptance test process and recommend actions to improve test methodology. Membership represented a cross-

section from the training systems development industry and included the following companies:

- o CAE-Link Corp
- o ECC International Corp
- o FlightSafety Services Corp
- o Hughes Simulation Systems Inc
- o Loral Defense Systems Division
- o McDonnell Douglas Training Systems Inc

Membership from the SPO consisted of two functional experts representing the disciplines of Engineering and Test Management.

The Cumberland Group, a subsidiary of Armco Steel, conducted an intensive four day workshop to train CPT members to analyze and improve the process. The Training Systems SPO agreed to fund the training for each CPT member. Team members gained a common understanding of the CPT purpose and were able to come to a consensus on how the acceptance test process is a summation of activities which must be completed in the course of providing a product or service. Effective working relationships were established and the team structure was created. Training provided the beginnings of an understanding of the Cumberland Process Improvement Model methodology.

THE PROCESS IMPROVEMENT MODEL. The objective of process management is to focus on the customers, determine what their requirements are, analyze how work will be accomplished, and identify and eliminate the sources of waste in the process.

The Cumberland Process Improvement Model consists of five primary steps leading to the elimination of nonvalue added components. The model stresses that quality problems are very often rooted in the process that produced them. A change in the process, therefore, is required to achieve meaningful improvement and not just merely eliminate the symptoms. This is the foundation upon which the process management approach to quality improvement is built. Following is a brief description of each step in the process improvement model.

Definition of the Improvement Opportunity: To develop a clear understanding of the team's task, desired expectations were clarified. A flow chart of all acceptance test activities was constructed to better understand the process. Finally, indicators (measures) of improvement were agreed upon to guide the team as it searched for areas of process adjustments.

Data Collection: A questionnaire, based on the measures of improvement was developed and used for data collection to move from the statement of the problem to a more complete description of the current process. Benchmarking of similar processes was initiated. Performance measures of several completed Government test programs were then documented for subsequent process analysis.

Analysis of Improvement Opportunities: Data collected from the previous step was used to identify and prioritize waste and focus efforts on the high payback areas. Waste is defined as any activity that does not add value to the process and was viewed as the primary opportunity for improving the process. In the final element of this step, the root causes of each major waste area were identified.

Development of Solutions: The intent here was to generate alternative ways to eliminate root causes of waste. The team concentrated on ways to significantly change the process instead of merely making minor adjustments. With no assumed constraints, the "perfect" process was visualized to form an understanding of what could really be achieved, even if in stages rather than all at once.

Improvement Recommendations: This final step was designed to improve the current acceptance test process through a series of recommendations resulting from solutions developed during prior analysis steps. Continual improvement is made by planning the modification, engaging the plan, then checking and making adjustments based on the results.

DEFINITION OF THE IMPROVEMENT OPPORTUNITY

The process of developing a clear understanding of the CPT's task and clarifying expectations for improvements in simulator testing was the team's first major assignment. The mission statement that follows was developed in order to clearly define the purpose and reason for existence of the CPT:

"We are the YW/Industry Partnership CPT, committed to continuously identify and promote implementable approaches to minimize the cost and time required for acceptance testing of aircrew and maintenance training devices and to insure that these devices support the users' needs."

The test process was initially defined as the primary means by which a training device is evaluated

for compliance of the design/product against required characteristics and system performance. Through verification, validation, and authentication, the adequacy of performance characteristics are determined along with identification of deficiencies in system performance. Acceptance testing is defined as any and all contractor and Government activities performed to verify device conformance to specified system subsystem performance requirements.

The test process provides contract closure, and allows training initialization. Yet, despite its importance, the test process and accompanying test documentation has been reported as byzantine at best. Many myths and misinformation abound. There is widespread belief, for example, in the following:

- o Acceptance testing contributes to schedule delay
- o The Government must witness all acceptance tests

The flowchart shown in figure 1 depicts typical test activities and may vary somewhat depending on a particular program's requirements. Review of the existing process revealed that there were several test repetitions, multiple Test Readiness Reviews (TRRs), and numerous possible delay paths.

Process indicators were used to measure the performance of the acceptance test activities. Two approaches were used to generate the process indicators. First, the CPT membership produced a list of parameters which measured the performance of the acceptance test effort based on specific testing experiences. The second approach was to define measures relating directly to the delay loops in the process flowchart. Finally, the two lists were evaluated with reference to the following criteria:

a. If the test process is revised, will the proposed indicators be able to measure the improvement?

b. Can the indicator be measured in real terms using objective results?

c. Can data be obtained from the companies, is it something likely to be measured and retained as part of the existing testing process?

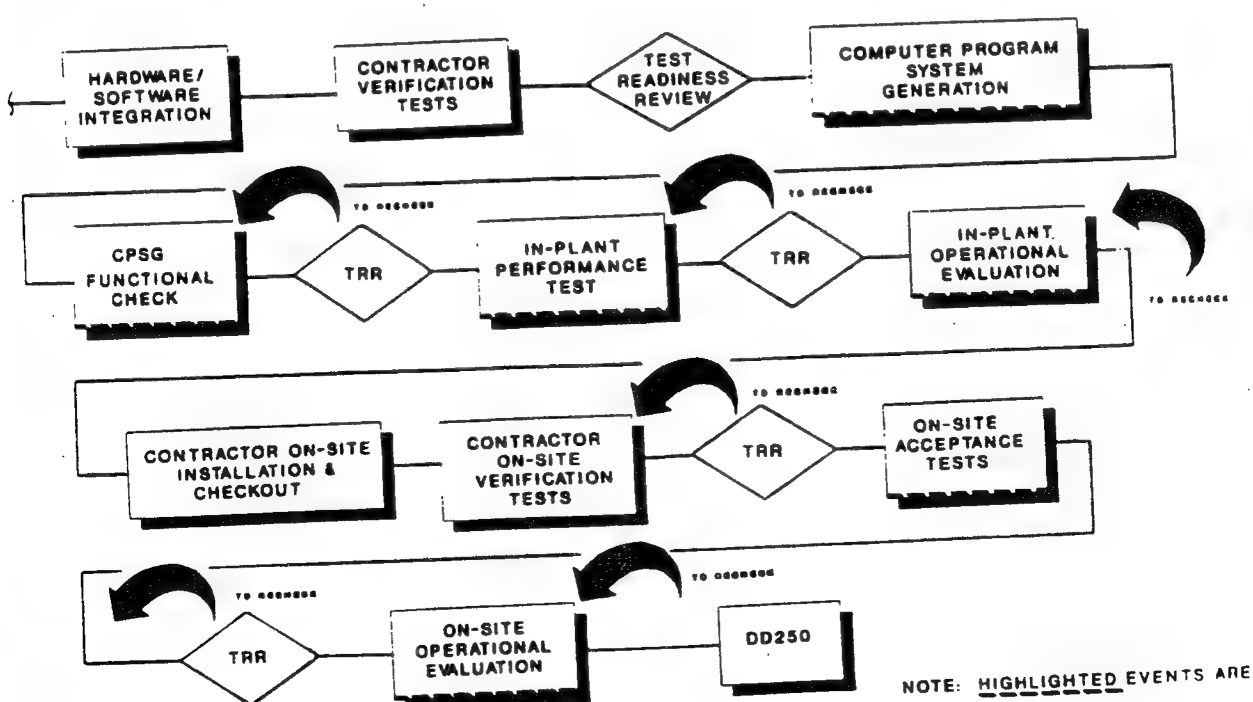

FIGURE 1. CURRENT SIMULATOR TEST APPROACH

d. What is the most important data to request? The final list of process indicators totaled 38 distinct measures. The CPT focused on the four top indicators to collect data for further analysis.

Test Milestones Met or Delayed: The first indicator was based on schedule milestones required to conduct a test program. Program and contract schedule events were chosen in anticipation that such data would be recorded and available.

Number of Test Discrepancies: The number of Test Discrepancies (TDs) generated during acceptance testing is a measure of the training device quality. To get more insight into the causes of TDs, data was requested to include total number of TDs, number of TD re-submits, number of post sell-off TDs, and number of TDs out-of-scope.

Number of Days in Test: The purpose of this indicator was to isolate schedule variances by measuring duration of key test events (planned days vs. actual days). From the results, the CPT selected three phases to measure test duration as a performance indicator. These were in-plant development tests and on-site acceptance and operational evaluations.

Test Documentation: The CPT membership considered test documentation excessive. The size of the test procedures, i.e., number of pages, was the means used to measure this excess. In addition, the detail to which the procedures were written was measured by the number of test steps per page.

DATA COLLECTION

After settling on which indicators to be used, it was then necessary to consider the possible sources of data for the information the CPT needed. In determining the selected programs, the CPT focused on recently completed test programs and the likelihood of gathering accurate data. Finally a questionnaire which focused specifically on the process indicators was developed and used to gather supporting data.

The raw data from the questionnaire was analyzed and incorporated into summary sheets. Several very important adjustments were made to produce the summary sheets. The first adjustment was to eliminate companies/programs that did not respond to the questionnaire and those who felt their process was different. In addition, programs were excluded if sufficient data was not available. For example, only limited data was provided for maintenance trainer programs apparently due to less stringent test requirements. Comparison data was therefore nonexistent. As a result, six military programs remained for further evaluation.

BENCHMARKING. The concept of "who does it best" is known as benchmarking. The approach was to identify possible candidates for the CPT to evaluate as "best." The benchmark selection criteria included stringent testing and the use of commercial practices relating to the CPT process indicators. Candidate sources were:

- o Airline simulator programs
- o Simulation industry
- o TQM award winners
- o Other TQM intense companies
- o NASA simulators

The replies to the CPT membership inquiries and questionnaire were extremely poor. Successive follow-ups by team members did little to elicit further responses. Many indicated they felt their testing approach was sufficiently different to make it unsuitable for our purposes. It rapidly became apparent that integration and test of a full flight simulator is a uniquely challenging task not commonly encountered in other industries.

At that point the team decided to focus on the commercial airline simulator industry as the candidate for "best". This was based on the fact that they buy/build a product similar to the Air Force, use commercial standards, and must pass stringent acceptance testing conducted for/by the FAA. Seven commercial devices provided data considered adequate for benchmarking.

ANALYSIS OF IMPROVEMENT OPPORTUNITIES

There is a fine distinction between a problem and an opportunity. In this phase of the CPT effort, as problems were substantiated, opportunities became apparent. The predominant issue was then to focus/select opportunities that satisfied the mission statement.

After being reviewed for omissions, the raw data was organized for the purpose of identifying waste areas in the test process and subsequently determining the root causes. The data was grouped according to the four process indicators and studied for information and/or conclusions that could be drawn from the data sets. The data was plotted to

obtain a visual representation and studied to identify relationships, trends and observations.

Each chart was individually reviewed to search for waste areas in the test process. Graphical analysis assisted in producing a better definition of the problems. The team used tabular data, histograms, the process flowchart, and comments on the questionnaires for identification of process waste areas.

For the reader with greater interest in the experimental design the complete data collection and analysis methods are contained in USAF TR-90-5000, 12 Dec 90, "Process Improvements in Training Device Acceptance Testing - A Study in Total Quality Management" available from Defense Technical Information Center (DTIC), Cameron Station, Alexandria VA 23661.

Eight critical waste areas were identified for subsequent root cause analysis. Root causes were uncovered by systematically questioning why the waste exists until the root cause is identified. This was done by asking "why" five times. This technique, while quite basic, allowed root causes to be determined for each waste area.

DEVELOPMENT OF SOLUTIONS. The solutions described are based on eleven months of intensive study, data collection, and analysis. With the knowledge obtained up to this point, the current test process flowchart was revisited. By removing all constraints, bias, and myths, then applying insight gained from the data, an idealized flowchart was generated to visualize a test process void of identified wastes. This new flowchart, in conjunction with the information gained from identifying root causes, provided the basis for developing solutions. Although the solutions are specific in nature, they are not intended to be perceived as the only solution but rather as the CPT's suggestions based on the research conducted. It should be noted that all solutions had a consensus of the CPT membership.

<u>Waste Area 1: Delay in start of test.</u>
The following root causes were identified by the CPT as being directly related to test delays:

- o Late Government identification of minimum training needs
- o Poorly defined requirements
- o Incomplete design
  - Requirements not complete
  - Data not available
  - Resources not available
  - Inefficient implementation of new technology
- o Manufacturing not complete
  - Government Furnished Equipment (GFE)/Contractor Furnished Equipment (CFE) not available
  - Inadequate subcontractor/vendor management
- o Hardware/Software Integration in process measurement criteria lacking

Program delays due to late Government identification of training needs often cause the program planning phase of the procurement process to be incomplete. Inadequate research during this period results in poorly defined phenomenon during later stages of design development. The problem is further compounded when the contractor accepts these nebulous requirements and consequently fails to perform to Government expectations. Thorough completion of the training requirements analysis prior to the release of the RFP will greatly assist in well-defined, realistic requirements to provide a sound basis for contractor scheduling, pricing, and technical performance.

Problems associated with the contractor's failure to complete the design prior to testing due to incomplete data may be decreased or eliminated by identifying mission data early during the program and establishing joint contractor/Government interpretation. This interpretation should then be formally included in the Design Criteria List (DCL). Early involvement of Sub ject Matter Experts (SMEs) will also help alleviate problems associated with a lack of data by providing an "on-line" data source during the design development phase. In addition, implementation of the data generation and management principles identified in the Simulator Data Integrity Program sponsored by the Training System SPO under contract AF33657-88-C-2168 should be considered to ensure accurate and complete data is provided by the weapons system prime contractor.

The problem of unavailable resources centers around delays caused by events leading up to and including Hardware/Software Integration which have been determined to be especially significant by this CPT. For example:

o Hardware/Software Integration suffers from poor planning and implementation.

o Ability to manage the Hardware/Software Integration process has been lacking.

o Start/stop criteria and in-process measurement tools have been non-existent.

Schedule risks associated with utilizing new technology in the device design can be mitigated by developing prototype testing procedures to mature the technology prior to Hardware/Software Integration. These procedures can be reduced on subsequent production quantities as the risk of the technology decreases.

GFE availability problems can be reduced by implementing a system in which the Air Force procures the required training system components from the prime weapons system contractor as soon as GFE requirements are known. An alternative is to have the Government include in the weapon systems contract the requirement to enter into an associate contractor agreement with the simulator contractor to supply the necessary components. Alternatives to using GFE should be explored such as the use of commercial components which are essentially equivalent to MIL-SPEC hardware items.

Inadequate subcontractor/vendor management problems are not in the customer's direct line of responsibility; however, the Government can influence the prime contractor to address this area to reduce the risk to testing. Suggestions by the CPT for industry improvements include:

o Avoid multi-level, multi-party subcontractor arrangements on major device components where the actual supplier has no direct link to the prime

o Establish a strong subcontractor/ vendor management team to take responsibility for the supplier's performance

o Use on-site representatives when necessary to closely monitor supplier performance

o Use Material Requirements Planning (MRP) packages to help schedule vendor delivery

o Develop reliable second sources for high risk components

o Insist on monitoring and reviewing major subcontractor performance on a regularly scheduled basis to identify potential problem areas

Waste Area 2: Redundant testing.

The following root causes were identified as contributing to the problem of redundant testing:

- o No Government recourse after buy-off
- o Improper engineering test procedures
  - Engineering procedures not repeatable
  - Results not documented

The customer typically views acceptance testing as his "one and only shot" at discovering all system problems. This results in aggressive testing by the Government to ensure the continued performance of the simulator throughout the required life cycle. The contractors can instill confidence in their product and thus lessen the need for extensive testing by providing a more comprehensive performance warranty package similar in scope to those currently available to commercial airlines.

Redundant testing often occurs as a result of poor contractor testing procedures. The Government does not accept Contractor Verification Testing (CVT) results as "final" and usually reruns a substantial portion of contractor test procedure. Confidence in contractor test results can be established by increasing the quality of in-plant testing and including advisory SME involvement during CVT. This solution prompts the contractor to conduct in-plant tests which are repeatable and well-documented. Consistent contractor test results will increase the likelihood of Government acceptance of the data generated and eliminate the need for repeating previous contractor testing. Failure to properly perform and document CVT also results in jeopardized on-site device performance and reduced profit due to attending schedule delays and additional contractor resources necessary to upgrade the device to an acceptable condition.

Waste Area 3: Detailed customer subsystem Performance verification.

The CPT identified the following root causes as contributing to overly detailed performance verification testing:

- o Contractor test results not available or documented
- o Traditional, bottoms-up test techniques
- o Performance risks associated with new technology

The need for detailed Government performance verification to the subsystem level can be eliminated by instituting improved contractor test procedures. Prototype tests should be developed for high risk, new technologies prior to Hardware/ Software Integration until a satisfactory confidence level is reached. Traditional bottoms-up testing should no longer be performed by the Government. Instead, these procedures should be completed during contractor testing. The procedures and test results should be thoroughly documented for Government review, thus allowing one time cost effective and efficient system level acceptance testing.

Waste Area 4: Test Discrepancies.
Examination of TDs as waste areas yielded the following root causes:

- o Lack of trained resources
- o Invalid test procedures
- o Poorly defined operational performance
- o Data shortfalls
- o Incomplete contractor testing

Proper training of test personnel in these areas is essential in limiting the number of discrepancies written against a given device. Proper training ensures that test procedures are properly set-up and performed and test personnel are able to sufficiently measure device performance against performance criteria. Implementing in-house training programs based on the principles of TQM to create a climate of pride, teamwork, and ownership has great potential to alleviate excessive write-ups and increase overall quality.

Poorly defined performance requirements also contribute to unnecessary TDs. This problem relates back to a failure of the Government to completely identify training needs early in the program.

A closely related problem is a lack of performance data. Data shortages can be alleviated by making SMEs available throughout the design, development, and contractor testing phases of the program. SME involvement in design reviews is especially encouraged to clarify design data assumptions and resolve ambiguities with the results then formally documented.

It should be noted that TDs are symptoms, not causes. Root causes which give rise to TDs have been identified and solutions discussed in several of the other waste areas.

Waste Area 5: Excessive test Documentation.
Contributing to the problem of excessive documentation, the following root causes were identified:

- o Documentation is overly complex and detailed providing for
  - Repeatability
  - Skill level
  - Support considerations
  - Test Matrix requirements
- o Documentation is not coordinated across contract requirements
  - Micro management

Overly complex and detailed documentation can be alleviated by writing engineering tests at the functional level. Greater emphasis should be placed in the requirements for contractor development of automated test procedures for such areas as aero and performance tests, initial conditions, avionics, nav-aids, diagnostics, etc. A further solution is to have Government testing at the mission level which eliminates the need for step by step procedures. Another solution is to examine the Test Matrix at design reviews to minimize the requirements for tests and demonstrations based on the evolving systems design.

Waste Area 6: Test Interruptions.
The following root causes were identified as causing schedule interruptions:

- o GFE/CFE spares not available
- o Schedule pressure
  - Acceptable risk
- o Poor systems analysis/solutions unsatisfactory
- o Customer facility not ready
  - Lack of control of the construction program
  - Lack of contractor design
- o Software update process errors

Test interruptions due to schedule pressure often result from allowing known problems to exist unresolved. The contractor should monitor these problems through the use of established risk management procedures, resolve TDs as quickly as possible, and ensure trained personnel are available in each specific program area. The determination of acceptable risk to enter into Government testing with known problems occurs during TRR. A more comprehensive analysis effort should be made at this time prior to entering test to avoid delays, disruptions, and waste.

A lack of GFE/CFE spares is often responsible for test interruptions. The Government can solve this problem by considering spares requirements when ordering components from the weapons system manufacturer.

Poor system analysis is the root cause of many test interruptions as unresolved critical TDs often result. An ad hoc team should be established to resolve "show stopper" TDs utilizing both contractor and Air Force resources as required.

Modification or new construction of a facility is most often accomplished via the Military Construction route (3300 appropriation funding). However, the ability to use RDT&E (3600 appropriation funding) should be exploited where new facility construction is a requirement. AFR 80-22 states that RDTT&E funds may be used to acquire industrial and RDT&E facilities needed by contractors to fulfill R&D contracts as authorized by 10 USC 2353. This has been interpreted to mean that where a facility is needed by a contractor in order to perform tasks required by a R&D contract, that facility may be provided through this funding.

Waste Area 7: Multiple test readiness reviews.
A singular root cause was identified generating multiple TRRs:

- o Failure of the contractor to be ready for test

Multiple TRRs are costly to both the Government and contractor, contribute to the length of the test schedule, and constitute a non-productive expenditure of test team resources. Data indicates that the contractor historically is not ready at TRR. Multiple Government TRRs can be avoided by placing the burden of test readiness solely on the contractor. The need for multiple TRRs should be re-evaluated and contract requirements written to reduce the number of TRRs accordingly.

Waste Area 8: Computer Program System Generation (CPSG).
The following root causes were identified as contributing to CPSG requirements:

- o Lack/weak contractor software tools
- o The requirement to accommodate changes

CPSG requirements constitute a lengthy and unnecessary waste of resources when large scale, complex devices are involved. Software tools and processes are available which provide the same level of confidence in the integrity of the software as CPSG. This is particularly true for those programs requiring Ada software language or otherwise require automated configuration management routines. Government certification of contractor software tool and processes for software configuration management and the capability to support changes should be accomplished prior to test. Certification would then allow for the elimination of CPSG requirements.

IMPROVEMENT RECOMMENDATIONS

The CPT is recommending fundamental changes to the acceptance test process and activities supporting that process. These recommendations are based on analysis of the current test methodology and solutions formulated by the team to eliminate the root causes for identified wastes. The recommended new process known as Simulator Test 2000 (ST 2000) is shown in Fig 2. When contrasted against the current test process (ref Fig 1), the elimination of redundant Government CPSG testing, in-plant performance tests, and on-site acceptance tests becomes obvious. Accountability will be improved by better aligning authority with responsibility for Government and contractor development test teams. Unnecessary testing will be eliminated, test documentation will be minimized, and the level and type of testing will be more focused on satisfying training requirements. In addition, a comprehensive and more effective test assessment will be realized without extensive TRRs. Test procedures will be elevated to the functional level and Air Force Subject Matter Experts (SMEs) will be made available to assist the contractor during systems development. Test functionality will not be reduced nor will test integrity be compromised as a result of the recommendations proposed in ST 2000.

The CPT concentrated on the task of improving the efficiency of acceptance testing. However, "testing" encompasses and is influenced by a much broader span of activity outside the formal test program. Program development tasks prior to acceptance testing were suspected by the CPT membership of masking problems which subsequently appear during or delay the start of acceptance testing. The data collected supports prior suspicions.

CPT findings show a major cause for delay in fielding acceptable training devices is due to activity that precedes the start of acceptance testing. In particular, recommendations made in the areas of design data, aircraft components, and Hardware/Software Integration are emphasized because of their known historical impact on the test program. Correction of these problems will largely avoid significant delays experienced on past programs.

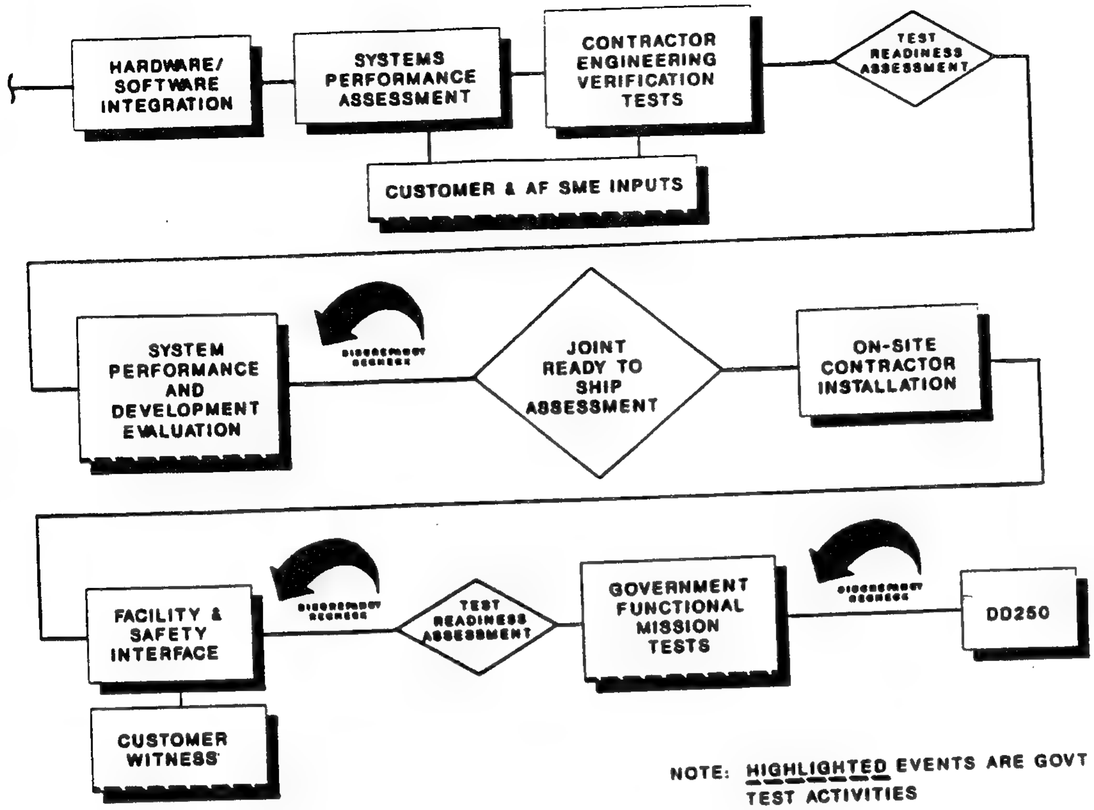

FIGURE 2. SIMULATOR TEST 2000

With regards to design data, the CPT recommended that SMEs be made available to the training device contractor early in the program to help resolve data deficiency problems and establish consensus on interpretation and application. Further, that the Government implement the Simulator Data Integrity Program study recommendations to ensure timely, accurate, and complete data availability to the training device developer from the weapons system design contractor. Also recommended is the use of more aggressive, comprehensive performance warranties to crystalize contractor liability and bolster Government confidence in contractor assertions to "meet the specification." This is hoped to radically reduce contract test requirements. Lastly, a well defined and realistic Training Systems Requirements Analysis should be developed prior to release of the RFP to establish a bound training tasks early in program development.

To relieve the schedule delays attributable to unavailable or late aircraft components, early identification of requirements (including spares) followed by obtaining sufficient priority for timely acquisition from the weapons system contractor is considered essential. Components could be manufactured or alternately provided by the training system developer via an associate contract agreement with the weapons system developer. Prime contractors are encouraged to strengthen subcontractor/vendor management processes to improve delivery performance and reduce the impact on device readiness. A repair pipeline, negotiated with the original equipment manufacturer prior to testing, may insure the availability of spares during the test program.

Significant recommendations to improve hardware/software integration include establishing an Industry lead CPT to investigate viable HSI in-process measurement criteria. Improved management of this important development step is critical to Contractor Engineering Verification Tests (CEVT). To mitigate technical performance and schedule risks use of prototype testing to mature new technology applications prior to attempted insertion into Hardware/Software Integration is proposed. To abate the impact of test interruptions, risk management programs must be developed and implemented to anticipate and man-

age possible causes. Training device development programs requiring new/modified facilities should consider tasking the development contractor as authorized by 10 USC 2353 to centralize contract engineering responsibilities to insure facility availability.

The CPT recognized that the contractor currently has every incentive to start Government test to see if he can "selloff" the device and save schedule. If testing fails to achieve the desired result, the contractor may find it more economical to resist corrections, attempt short term solutions, and hope test schedule concerns will cause the Government to weaken its position.

However, the CPT also believes that exceptional contractor test performance should be rewarded. Conduct of an effective, well planned test program is a worthwhile objective. The creation of contract incentives to accomplish this, however, is dependent upon several variables including the basic nature of the testing (development vs. production), the type of contract (cost vs. fixed price), and the type of incentive (i.e., objective performance incentive versus subjective award fee incentive). These factors, along with other pertinent facts, must be weighed when trying to assess the ability to create a "real" contract motivator.

Development Testing - Cost Type Contract - Award Fee: Because of the very nature of a development program, it would be extremely difficult to structure a performance incentive which would be meaningful. Development testing by its very nature is intended to surface problems before the design is frozen and moved into production. The key is solid test planning and analysis in order to minimize surprises. These areas tend to be quite subjective when attempting to establish measurement criteria. Award fee provisions would allow tailoring of the incentive from period to period as the program progresses and provide multiple opportunities to reward performance.

Production Acceptance Testing - Fixed Price Type Contract - Performance Incentive: In a production environment, test requirements are usually quantifiable. Because of this, the Government's ability to write a meaningful incentive at the time of contract award is much greater. A concern remains that the incentive being structured is sufficient in terms of dollars or corporate visibility to be an effective motivator and is in balance with the remainder of the program. From a cash flow or liquidation standpoint, the contractor is still motivated to push for contract buy off in order to claim progress payments and profit. Additionally, the incentive must be justifiable in terms of overall savings to the Government (i.e., reduced Temporary Duty, more efficient use of personnel, etc.).

The CPT recommended that initiatives begun by The Training Systems SPO on the Simulator for Electronic Training (SECT) and Special Operations Forces Aircrew Training Systems Programs (award fee) and the Digital Radar Land Mass System (performance incentive) under development for the F-16C/D weapon system trainer be continued and applied to all new acquisition programs. The need to monitor results of programs where incentives have been applied is considered extremely important to ensure the level of value is worthwhile to the contractor, that the incentives remain realistic and achievable, and experience gained through their application is reinvested in future programs.

CONCLUSIONS

The premier improvement to simulator and maintenance trainer test process has been identified as Simulator Test 2000. Reforms to reduce Government test, strengthen and reallocate contractor test responsibilities, refine test documentation, and discrepancy management encompasses major CPT recommendations.

For any recommended process change to be considered for implementation, a measurable improvement must be expected. If there is a significant anticipated benefit as a result of the new process, a high degree of motivation to adopt the new process will be present.

A comparison of the current simulator test approach shown in Fig 1 and referred to here as the "Idealized Weapon System Trainer (WST) Test Program", can be made to the ST 2000 process. The Idealized WST Test Program assumes that once testing begins, it progresses and is completed without delays or interruptions. This test program includes CVT, Performance and Acceptance Tests, and in-plant as well as on-site Operational Evaluations as depicted in Table 1. The total test effort of forty-eight (48) weeks required by the idealized WST test program can then be compared to estimates for a WST using the ST 2000 process as shown in Table 2. It can be seen that the reduction of the total test effort from forty-eight (48) weeks to thirty and one half (30.5) weeks represents a savings of approximately thirty-seven (37) percent.

Table 1. Idealized WST Test Program

	IN-PLANT			ON-SITE		
TESTS:	CVT	Performance Test	Ops Eval	Acceptance Test	Ops Eval	TOTAL
WEEKS:	20	18	2	6	2	48

Table 2. ST 2000 Process

	IN-PLANT			ON-SITE	
TESTS:	System Assessment	CEVT	SPADE*	Functional & Mission Tests	TOTAL
WEEKS:	1.5	20	6	3	30.5

* SPADE = System Performance and Development Evaluation

The consensus of the CPT members is that with the adoption and implementation of the ST 2000 process, a significant savings in resources can be realistically expected if all elements of ST 2000 process are implemented.

Additionally, if the other recommendations and suggested changes are also implemented, increased efficiency in training device acquisition programs can be achieved. These are outside the formal test phase, but directly affect the start or progress of testing. The potential savings to cost/schedule which can be achieved by implementing these changes are not to be overlooked. The largest waste in most military training device development programs occurs, for a variety of reasons, prior to the device being ready for testing. Data collected showed that on average military programs are 132 days (26.5 work weeks) late prior to beginning of test. The elimination of this waste would result in cost and schedule overrun savings of approximately eighteen (18) percent over the life of a planned thirty-six (36) month program.

The Simulator Test 2000 concept has been embraced by the Training Systems SPO and implemented on new program starts. The Simulator for Electronic Combat Training Development Program, the Leading Air Training Command Electronic Warfare Officer Training Initiative, and the Euro-Nato Procedures Trainer Modernization Program are both structured to take full advantage of the ST 2000 process.

The development requirements for aircrew training devices for the Joint Surveillance Target Attack Radar System will similarly adopt the ST 2000 improvements and an on-going contract for C-17 maintenance training devices is being modified to take advantage of test cycle process improvements and reduce government test program requirements (man-months) by an estimated 50 percent.
The most significant process change is the customer's agreement to accept CEVT test results. Repetition of these types of specification compliance tests by the Government are no longer a requirement. This commitment eliminates the single largest cycle of customer testing from the current acceptance test process.

In point of fact, ST 2000 places the responsibility to thoroughly execute CEVT squarely on the contractor. It must be conducted to the same level as required for developmental performance testing previously conducted by the Government. This means that test results must be documented, verifiable and repeatable. Failure to execute stringent, valid testing with documented results will motivate the customer to demand a repeat of previously run tests and will again require 100% witnessing of CEVT.

If the contractors do not perform their part, the customer has no alternative but to revert back to the existing test philosophy. The customer has extended the opportunity, the contractor must aggressively respond for ST 2000 to be viable.

ENDNOTES

1/ Winter, F.J., et. al, "Process Improvements In Training Device Acceptance Testing - A Study In Total Quality Management" USAF ASD TR-90-5000, Dec 12, 1990

2/ Shaw, J. and Lloyd, William "Bridging the Information Gap." Proceedings of the Eleventh Interservice/Industry Training Systems Conference, (November 1989)

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That the development of training device acceptance test improvements have proceeded so rapidly, to such successful outcome with such a far-reaching impact, is a testimonial to the vision, skills, and dedication of this highly motivated and professional team. Those useful insights contributed greatly to the development of this paper.

COMBAT PERFORMANCE TRAINING and PIPELINE CONNECTIVITY
The ASW Aircrew Model

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ABSTRACT

The Anti-Submarine Warfare Sensor Operator (AW) in the Navy's VS, VP, HS and HSL communities, performs a function which is not only mission-critical, but one in which he alone has been trained. Solely responsible for the detection and classification of subsurface contacts, the skill, judgement and training of this individual is the cornerstone of an ASW prosecution.

The AW training "pipeline" reflects the traditional military approach to training, which emphasizes task-driven procedural instruction in the operation of systems and equipment. This approach neglects the development of higher order cognitive skills necessary to the creation of expert operational performers. This forces individual squadrons to use On-the-Job Training (OJT) to make up for this shortfall. OJT however, is largely an ad hoc arrangement, only as good as the training credentials of individuals within a given command, and conducted on a not-to-interfere-with basis with preparations for the next readiness assessment hurdle.

The Navy cannot afford to train its operators and tacticians of the 21st Century in this traditional manner. Inefficiencies in current methods will be magnified in the future, and could inhibit emerging technological advantages. A shrinking budget, cutback in forces, reduced opportunities to practice, and growing complexity of the threat taxonomy, all call for a complete overhaul in the way the Navy trains and supports this critical mission specialty.

INTRODUCTION

"It cannot be too often repeated that in modern war, and especially in modern Naval war, the chief factor in achieving triumph is what has been done in the way of thorough preparation and training before the beginning of the war."

- Theodore Roosevelt: Graduation address, U.S. Naval Academy, June 1902

The notion that there isn't going to be time to get ready once a conflict begins, presents a sound argument for manning military forces with personnel who not only have the basic procedural skills required to operate equipment, but also the tactical decision-making skills required in combat. Given that a trainee is transformed into a fleet operator on graduation day, the Navy's training pipeline is presented with the clear challenge of developing fleet operators with ***combat performance and tactical decision-making*** skills. The objectives, methodologies and evaluation criteria between procedural and performance training are significantly different.

This paper discusses a few of the preliminary conclusions from an ongoing study of the ASW Aircrewman training pipeline. The study's objective is to assess current training methodologies in order to identify wasteful, duplicative, unnecessary, ineffective or outmoded methods. The ultimate goal is to develop a continuous training system, which creates and sustains a high percentage of expert performers, capable of meeting the threat environment of the 21st Century.

A conclusive assessment of any training pipeline must determine whether there is measurable evidence of the value of the current system, and whether previously established goals

and training methods still continue to be important. Military planners need to approximate the missions, operating environment, threat capabilities, and operational weapons/sensor systems of the future before an effective training process can be defined. This paper attempts to "bound the problem" by offering preliminary conclusions and recommendations with respect to the following areas: Performance Drivers, Personnel Screening and Selection, Training Pipeline Connectivity, Procedural Training Dominance, Mission Planning, Post-pipeline training, Performance Feedback, and Archives Development.

THE TRADITIONAL APPROACH

The Navy's current training development strategy was defined to a large extent by the proliferation of the Instructional System Development (ISD) methodology of the 1960s, embraced by Naval Aviation in the 1970s. This approach has been used successfully in maintenance training, where economies have been realized through the establishment of rigid standardized procedures.

The ISD approach was built on the premise that an individual's performance would largely be procedural in nature, (e.g. the maintenance and operation of systems and equipment), and that an appropriate program of training could be developed by first identifying and segmenting these procedural duties, and then developing specific training for each independent tasks and sub-task.

The key strength of this approach is its simplicity. A "task listing" provides certainty when actual performance requirements may be ambiguous or difficult to describe. Simplicity however, is also this system's biggest detractor. The system fails when it is relied upon to teach higher order cognitive processes associated with tactical decision-making. Simulated ASW missions, for example, conducted in Weapons Systems Trainers (WSTs) and on instrumented ranges, found that pipeline graduates have difficulty visualizing tactical situations, prioritizing objectives, handling complex decision-making, coordinating with other crew members, and projecting threat actions. Each of these skills are critical to performance in combat. Moreover, while an acoustic operator must understand oceanographic theory as well as the procedural tasks associated with the operation of his equipment, what separates the novice operator from the "expert performer" are a largely undefined, but clearly evident group of advanced level cognitive skills, that the traditional training system does not recognize, or routinely develop in its graduates.

Determining the cognitive skill requirements for fleet operators is more difficult than identifying the expert performers from their counterparts. Everyone in a given command usually knows who the operational standouts are. It's taken for granted that these individuals have mastered the procedural aspects of their jobs. It is during demanding tactical or emergency situations, however, that the superior performance of these individuals is most conclusive. When faced with a crisis, they shift into "auto-pilot", screening and prioritizing information, processing relevant details, handling complex tasks without stopping to think about individual steps, taking decisive action at a pivotal moment and developing contingency plans for anticipated conditions. It is every Commanding Officer's goal to saturate his command with talent like this, yet while individual ships, submarines and squadrons usually have a number of these individuals at their disposal, it is usually the result of On-the-Job Training (OJT) or (personnel) detailing. The problem with relying on either of these sources is that OJT has wide variations in quality, frequency, standardization, and priority between commands, and personnel detailing doesn't prepare operators, it merely shifts talent between commands. The bottom line is that a training pipeline that fails to recognize the difference between performance training and

procedural training, creates a lower aggregate number of "expert performers", and consumes time and resources, producing graduates at a higher training cost than is necessary.

Key questions which the current training pipeline haven't answered are: What are the true performance-related skill requirements for a successful fleet operator? How does one go about developing a training strategy which stresses the cognitive skills critical to combat?

PERFORMANCE "DRIVERS"

Essentially, two key factors determine the potential performance capabilities of an individual: innate ability (what is "known") and experience (what is "learned"). Training (instruction, practice & feedback) is the process used to develop experience. Therefore, creating a system which is capable of producing expert performers requires an appreciation for the forces at work, specifically: innate ability, experience, and training. Understanding how to isolate, develop and nurture each of these is a first step in the design of a functional model for creating "expert performers".

Innate ability. Intelligence, motivation, attitude, maturity, perseverance, concentration, logic, and analytical proficiencies all play strong roles in the development of advanced level cognitive skills so often found in expert performers. Increasing the pool of personnel with the right mix of these talents for any specific skill area are recruiting, screening and personnel management (detailing) issues, which profoundly affect the cost of operator training as well as the level of expertise in critical mission specialties within the fleet.

Experience. A common denominator among many "expert performers" is the rich library of previous operational experiences they have internalized. These cognitive blueprints provide them a reference which they are able to access and modify when participating in demanding tactical scenarios. Highly experienced operators with a rich experience base have more streamlined decision-making skills, increased ability to anticipate threat actions, better organization and retention of relevant information, and enhanced ability to handle multiple/complex or parallel tasks.

Training. Once a basic foundation has been established in the primary skills, theory and procedural tools required to understand how to function as an Aircrewman, the capstone to the process of creating an expert performer is development of advanced level cognitive skills (e.g. judgement, tactical decision-making, et. al.). Accepting the principle that what separates the "expert performers" from the novices is development of an in-depth cognitive library of performance experiences, then the ultimate goal of an effective training system should be to systematically expose trainees to as many diverse and operationally significant learning scenarios as possible. This would include both direct participation in a variety of operationally realistic practice events, and the study of lessons learned from archives of operational exercises. Key to the development of this kind of training approach, are the following elements:

1) clearly defined performance objectives,

2) rigorous (student) mission planning,

3) observation, reconstruction and analysis by qualified "experts".

4) immediate diagnostic feedback and performance accountability, and

5) insertion of lessons learned into accessible archives for future reference.

Given this broad outline of the elements necessary to create expert performance, let us take the current AW training pipeline, as a representative model to current training philosophy, and determine how well it measures

up to these standards.

AW TRAINING

"We learn how to do things by doing the things we are learning how to do."
- Aristotle, *Ethics*

Overview of the AW training pipeline. Figure 1. provides an overview of the present training pipeline for ASW Aircrewman. During recruit training, a functional skills exam ("ASVAB" test) is given to all recruits. The score on this exam, which consists of basic mathematics, general science, arithmetic, mechanical aptitude, etc..., makes a recruit eligible for various job specialties and further training. Those designated to become aircrewmen are sent to the Naval Aircrew Candidate School (NACCS), in Pensacola Florida. Here they receive additional general military instruction along with aircrew-specific training in swimming, water and land survival, general aviation fundamentals, etc...

Following graduation from NACCS, AW trainees start the 11 week AW "A" School, which has as it's main focus, procedural training on the 14D1 generic ASW positional trainer. Based on their grades at this school, they are split into the various Air ASW communities (e.g. VS, VP, HS and HSL), and receive orders to the Fleet Aviation Support Operations Groups for basic acoustic and non-acoustic sensor procedural skills training. Finally, they are assigned to a Fleet Replacement Squadron where they learn how to operate the equipment they will be using in the fleet.

Personnel Screening and Selection: Presently, the only selection criteria used to select AWs from the general population of new recruits, is a minimum established score on selected portions of the ASVAB exam. The test formula (GS + AR + 2MK), which takes the General Science (GS), Arithmetic (AR) and Math Knowledge (MK) portions of the ASVAB, and was designed to provide a predictor of the ability

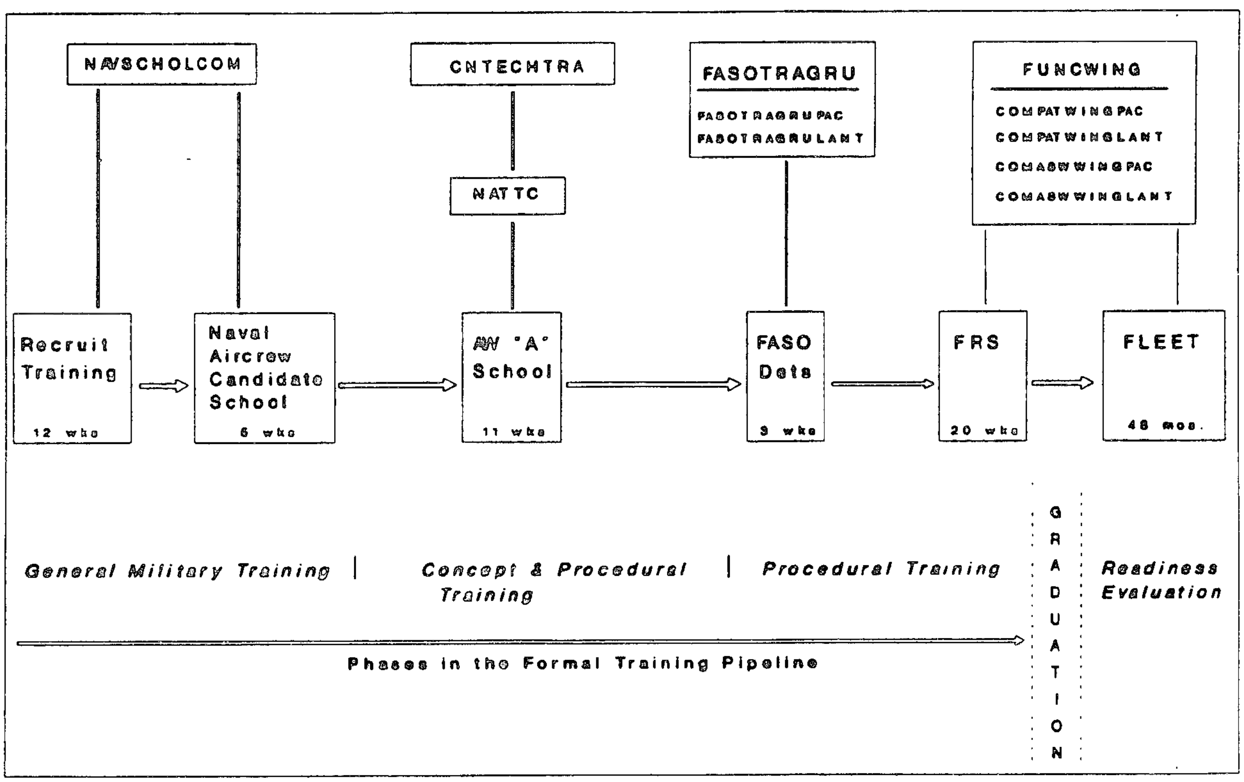

Figure 1. AW Training Pipeline. *Fifty-two weeks of GMT and Procedural training, under 4 separate administrative commands.*

of a trainee *to graduate from the AW "A" School*, and was not designed to identify individuals with (potential) performance skills required in the fleet. If the skills required to graduate from AW "A" School were good predictors of fleet performance, then this would not be a problem, however as we'll see in a moment - this is not the case. The issue is that there is no credible model of "expert" performance in the fleet, from which one can develop a profile for personnel screening and trainee selection. This forces the Navy to start with a random sample of individual ability, motivation, attitude etc.... Private industry has long recognized that certain personality types perform better in some jobs than others. The insurance industry, for example, screens applicants for sales jobs using a personality profile of its top salesman. They look for specific levels of confidence, self-reliance, motivation, perseverance, level of nervous energy, and the need for social contact. By establishing a template of the personality make-up of their most successful performers, they have a blue-print for hiring potentially successful personnel. Certain key strengths are better suited to any particular job, and the military is no exception.

Performance profiles do not exist for military operators in the field of tactical decision-making. This means that recruiting, selecting, screening and detailing decisions are being made without this criteria in mind, at a predictably higher training cost than would otherwise be necessary. The potential exists to lower training costs by identifying those cognitive skills existing in expert performers by job specialty, and building a screening mechanism tailored to select recruits with those abilities and motivations.

Some have argued that increasing the acceptance threshold on the already existing ASVAB test would generate better operators. They point to statistics in pipeline attrition and re-training (night school) as the basis of their recommendation. However this alternative has no foundation. Current attrition statistics in the pipeline, (excluding non-academic items such as disciplinary action, et. al.) are less than one percent. The explanation for this low rate, simply put, is that the evaluation criteria and competence naturally sought the level of training.

Pipeline Connectivity.

The organizational structure of this pipeline shows that the student enters and exits schools operating under four separate administrative Chains of Command, (NAVSCHOLCOM, CNTECHTRA, FASOTRAGU, FUNCWINGS) with various charters, mission statements, curriculum objectives, etc.... Coordinating these various programs of training is difficult for a number of reasons, not the least of which is their physical separation, and the very different objectives and operating procedures of the various Administrative Chains of Command. No single training strategy is in place that governs the process, and while the participants attempt to coordinate on an ad hoc basis, no dedicated pipeline "model manager" exists to oversee that these programs are mutually supportive.

Attempting to implement a material change throughout the training pipeline is not an insignificant feat. Each of the administrative chains of command have their own operating environment, change procedures, lines of authority and communication, funding sources, and perceived responsibilities. Furthermore, implementing a change in one end of the pipeline, mandates that the other players change their curriculum too. It's as if a house were being built by four different architects, each assigned one wall and a portion of a roof, and each with a vision of what the final structure should look like. Two solutions come to the forefront:

(1) Provide responsibility to a single architect, for the entire project; or (2) Make

assignments based upon sequential project elements (refer to Figure 2).

Implementation of either of these proposals would mitigate the connectivity issue, yet there are tradeoffs involved with each. Solution #1 relies on a single entity for the success or failure of the project. This has advantages associated with control, coupling of authority and responsibility, and single-point interaction with the end-user. Solution #2, requires communication among the participants to ensure continuity, but distributes the burden of training, and may decrease the chances of an inherent bias of a single entity.

The pipeline, as it presently exists, is unnecessarily complex - and while the sheer number of trainees it produces means that some of them are being adequately trained in spite of the process, the Navy can no longer afford the luxury of wasting resources, particularly if it is going to operate in the future with much smaller forces than they have grown accustomed to. Either a single training facility is called for, or the existing training facilities must develop a training a clear training strategy.

Dominance of Procedural Training.

Given the various knowledge requirements of an expert AW, (primary skills, theory, procedural and cognitive), procedural training dominates the training pipeline, beginning with the AW A-School through formal graduation from each individual Fleet Readiness Squadron. At the A-School, for example, the principal curriculum driver is the 14D1 trainer. This device is used extensively to teach, practice and evaluate procedural skills related to the operation of this equipment. The 14D1 is a generic trainer that does not replicate any hardware the trainees will see or use in the fleet. The student's ability to control and manipulate the 14D1 however, accounts for over 60% of the final grade at the A-school, and ultimately plays a role in assignment decisions with respect to the various Air ASW communities. While the FASO and FRS training programs do have access to Part Task Trainers (PTTs) and Weapon Systems Trainers (WSTs) which mirror the equipment used in the fleet, a similar situation exists in that the curriculum is almost exclusively procedural driven. This situation forces fleet squadrons into the position of developing the tactical decision-making skills

Responsible Party		Assignment	Application to Training Project
Solution #1	*Solution #2*		
Architect "A"	Architect "A"	Foundation	*Primary Skills*
" "	Architect "B"	Frame	*Theory/Concepts*
" "	Architect "C"	Appliances	*Procedural Tools*
" "	Architect "D"	Finish Work	*Cognitive Skills*

Figure 2. Project administration example.

quired of an actual mission. Fleet squadrons are not provided the resources to adequately meet this obligation.

Post-pipeline Training (Squadron OJT). The strategic bombing of Japan during WW II provides a conspicuous example of the effectiveness of continual, well-supervised practice in tactical operations. The object of bombing was to destroy the enemy's facilities for producing war goods, particularly those hardest to replace. Many of the plants were small, requiring extremely accurate bombing. The value of the strategic air forces depended upon how many targets they could destroy in a given time.

The training of the bomber crews had an important effect in all of these factors. Initial training was important, but Analysts in the Operations Research Group assigned to Admiral E. J. King's staff, clearly determined that a much more important factor was the continuous practice and diagnostic feedback provided to crews. Previous to their analysis, it was widely held that an operational crew could practice bombing over an enemy target just as easily as it could over a practice target, and that it would not be profitable to reduce the number of bombing missions per month to allow for practice time. However, the fact that diagnostic feedback from practice bombing was more immediate and detailed than operational bombing, allowed crews to learn more quickly of their mistakes. Operations analysts assigned to the project determined that a ten hour practice over a trial target, for instance, provided significantly more experience than a ten-hour operational mission. The resulting figures of bomb accuracy after immersion in a training regimen of practice bombing showed a ten-fold increase in destruction of enemy installations in November than was possible during the previous August. In other words, one plane in November, had the destructive power of an entire squadron during the previous August. It is important to note that the collection and analysis of data, which served as the foundation for performance evaluation, was transparent to the operational aircrews, and did not prevent them from gaining proficiency through continuous practice. [1]

By contrast, the existing Post-FRS (squadron) phase (refer to fig. 1), is more appropriately entitled "Readiness Evaluation" vice Post-FRS training, because virtually every Weapon System Trainer event is used to perform a Readiness Qualification. There is a wide-spread belief on the part of most administrative staffs that Readiness Qualifications provide training opportunities. Ironically, the two are diametrically opposed. Proponents of the current system argue that sitting in the trainer, "doing the job" is by definition: Training. Key variables are missing however which prevent this from being true. First and foremost, a key element which is missing is the ***"right to fail"***. In a NATOPS check-ride, or Operational Readiness Evaluation (ORE) for example, the inviolate objective is to pass the evaluation. A key to success is to prevent weaknesses from becoming apparent to the evaluator. Those being evaluated are coached not to ask questions - one hides imperfections if the objective is to get a discrepancy-free grade. Secondly, the concept of element training is lost when every event is run uninterrupted from beginning to end. If radar targeting is only one portion of a canned WST scenario, and one manages to struggle by that phase - no matter how poorly, it is not practiced in lieu of going on to the next required mission segment. Thirdly, when operating in a team environment, certain members of a crew always get preferential treatment and the training session usually emphasizes that training at the expense of other members requirements. In many of the Air ASW squadrons, for example, a common complaint was that most training revolved around "pilot proficiency", (e.g. instrument work, deck landing quals, in-flight refueling, formation, etc...). Next on the agenda was

tactical training - usually designed around the Naval Flight Officers. While this may sound like valuable training for AWs, other than designing the search pattern, the Tactical Coordinator's job doesn't really begin until after the AW has detected and classified the target - a process that can be subverted if contact is artificially generated, or an "easy" target is used just to get the tactical problem going. These hurdles have to be understood by training developers, so that they can ensure that readiness measurement doesn't prevent readiness development.

Mission Planning.

In preparation for the battle of the Nile, in which Admiral Nelson defeated the French fleet at anchor under the command of Vice Admiral Francois Brueys (1 Aug 1798), Nelson did something that Brueys had not: he had spent months at sea not merely drilling his force, but discussing and planning the battle. His captains all new his plans. He was to write before the battle of Trafalgar that "something must be left to chance", but nothing was left undone that could be foreseen. [2] General Eisenhower, in preparation for the Normandy invasion was quoted as saying: "... planning is everything, the plan is nothing." Both of these great military leaders understood the value of the planning process. It forced one to project threat capabilities, understand their intentions, anticipate their actions and develop contingencies. Air ASW units do surprisingly little mission planning. As a result, these skills are not emphasized adequately in the training pipeline. During actual operational exercises, mission planning is often confused with briefing, which turns into the passive activity of "getting briefed". Aircrews rely on others (ASWOCs and ASWMODs) to develop their plans. Insufficient time is taken to prepare for a mission. A checklist mentality has replaced thorough preparation as a standard practice for getting ready for an ASW exercise. The pipeline doesn't train its operators in the skills of mission planning because many of its instructors don't know how to do it. It's a lost skill that needs to be rekindled, because it is a key experience-builder that develops cognitive blueprints, which ultimately leads to expert performance.

Performance Feedback.

Since the introduction of Operations Research and Operations Analysis, during WW II, the U.S. Navy has refined and relied upon the OR/OA process to develop tactics, identify system requirements, and approximate conditions of readiness. In a large sense, these skills are vital to the efficiency and capabilities of a military force, because there are three basic determinants to whether a weapon will land on target: **Tactics** (Doctrine/Procedures), **Systems** (Equipment/Hardware) or **Training** (Personnel Capabilities). These three constants form a triad which decide the outcome of battles, oftentimes before they have started.

The Tactical Development and Evaluation (TAC D&E) process relies heavily upon OA principles to measure and evaluate the effectiveness of proposed or existing tactical doctrine. Naval Test Centers utilize these methods and techniques to evaluate systems and equipment to be introduced into the fleet. Current training programs however, have failed to implement this methodology.

The building blocks for this analytical process are the **Measures of Effectiveness (MOE)** and **Measures of Performance (MOP)**. Effectiveness has to do with results of given actions, without regard for the methods used to gain results. An action is effective or successful if the results meet established objectives. Performance has to do with the knowledge, training and skill of personnel and the methods, procedures and tactics they use to meet an objective. Performance is successful if the best procedure or tactic was selected and executed skillfully - regardless of the outcome. Success is in making the best choice.

as MOEs and MOPs have different teria for success, they must be assessed fferently. MOEs determine how often the sults were successful. MOPs however, :imarily evaluate skill and competence, ·gardless of the outcome. This usually requires nalysis by a highly qualified on-scene observer vho can note methods, procedures, and ntentions, and form subjective evaluations based ıpon his expertise. [3] Thus, if training professional are to implement OA principles into their methodologies, they would use Measures of Performance, and those techniques associated with assessing MOPs.

While there is no clear OA influence in the AW training pipeline, during the last month of the FRS, when some elements of performance-based training begin to surface, the underlying evaluation criteria is MOE vice MOP-based. For example, once training crew assignments are made, the students conduct a series of Weapons System Trainers, covering different mission objectives and principles. In the VS and VP communities, these evolutions typically take a full eight hour day of briefing, execution and debriefing. Each of these trainer periods have certain unwritten "rules", namely: every mission is 3 hours, every mission generates contact, every mission results in a kill, and every mission runs the full period before feedback is provided. This process rewards a "kill with a qual". In other words, the objective is a successful attack; if one meets the objective, one successfully completes the WST. This methodology, by definition, is an MOE-based process. Unfortunately, as was pointed out earlier, development and assessment of training, skill and knowledge components ought to use MOP methodologies. Training system administrators know whether or not a kill was achieved, but do not know how to develop MOP evaluation criteria. An MOP-based approach recognizes the value of intermittent feedback in WSTs, during the conduct of the training event, to correct critical mistakes, practice essential fundamentals, and create opportunities for trainees to internalize and build a library of tactical experiences. Transitioning to an MOP system from the institutionalized (MOE) methods won't be easy, and will take an understanding of the critical issues by senior administrators, a clear policy change, and a concerted effort at retraining instructor staffs.

Lessons Learned Archives.
Perhaps the single biggest contribution that could be made in the area of ASW Aircrew training, would be the establishment of a tactics library and mission planning center for its squadrons. No such facility exists, and one is sorely needed. Presently, each individual squadron attempts to maintain as many tactical publications as possible, in their own vault facilities. However, this archive is purged frequently, to get keep it to a manageable level (this normally means one cruise box, which can be carried and stored aboard ship). Experienced fleet exercise analysts are unanimous in stating that there are very few new lessons learned, the mistakes that any particular unit will make have been made by others in the past. Hundreds of valid TacMemos, TacNotes, Exercise Quicklooks and Post-exercise reports have been written which contain invaluable tactical, procedural, and operational lessons learned. Squadron operators must have easy access to these documents in order to gain experience from the trials of others. This is the cheapest form of experiential training - and arguably, one of the most important.

SUMMARY and RECOMMENDATIONS

"Combat training is also two-sided, that is, both mechanical and creative."
- Captain Wayne P. Hughes, Jr. USN (Ret.)
Fleet Tactics, theory and practice

The AW training pipeline is made up largely of procedural training curriculum, taught and managed by individual "school houses"

operating under separate administrative chains of command. Theoretically, the AW trainee sequentially progresses through this pipeline, building upon knowledge learned in previous commands, and gaining primary skills, theoretical knowledge, procedural tools and cognitive skills along the way. The existing pipeline however, relies almost exclusively upon traditional methods of training, emphasizing task-analysis driven curriculum which focuses on procedural skills.

While the specific factors which separate the "expert performers" from their contemporaries need to be definitized, the following characteristics are postulated: increased exposure to complex mission scenarios coupled with expert diagnostic feedback, immersion in an operationally oriented environment that rewards achievement, sufficient emphasis and opportunities to plan and rehearse mission scenarios, and access to lessons learned from other exercise events. Implementing these changes will take an agreed upon cradle-to-grave training strategy, and a single training model manager who has detailed knowledge of critical Measures of Performance, and the authority to reshape existing training methodologies.

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[3] Measures of Effectiveness (MOE) / Measures of Performance (MOP) Catalogue. Naval Tactical Support Activity, Washington D.C., 1 April 1988.

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TABLE COMPUTER-BASED TRAINING (TCBT): An alternative to ralized training without a loss of training effectiveness

Robert C. Bruce and Robert R. Woods
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ABSTRACT

It is no longer necessary to be restricted to a centralized rning center with local area networks (LANs) and large file vers when presenting computer-based training (CBT) programs. hnology has advanced to the state where training can be packaged ppy diskettes, forwarded to remote work sites, and presented low-end personal computers. Individual trainee performance data n be captured in real-time, prescriptive branching initiated, and rformance summaries returned to the responsible agency.

This paper presents the technology recently applied to a omputer-based training (CBT) program developed for world-wide issemination. This recently completed program resulted in a 40-hour technical analysis course being packaged on 12 double-density (360KB) floppy diskettes: 10 courseware and two executive presentation diskettes. This course is supported by a student kbook which provides all adjunct reference material, job aids, self-graded quizzes, and practical exercises. Trainee performance data is captured in real-time, stored in a database file on the hard disk, and then uploaded to the floppy diskette at the completion of the training program for return to a centralized training facility (this data may also be stored directly to the diskette to increase student mobility between workstations). This performance data is then available for external course validation, analysis of training effectiveness, entry into the individual trainee's record, and the generation of associated training reports.

INTRODUCTION

Baseline research was conducted as early as 1961 in evaluating the effectiveness of individualized instructional programs. Among the better-known and widely implemented systems for individualizing instruction are: Individually Prescribed Instruction (IPI) (Glaser, 1968; 1970); Individually Guided Education (IGE) (Klausmeier, and others, 1977); and the Utah System Approach to Individualized Learning (U-SAIL) (Hales, 1978). All of these approaches strive to actively involve the student in the learning process, allow students in the same class to be at different points in the curriculum, and permit the teacher to give more individualized instruction.

In the late 1960s and early 1970s, the National Science Foundation (NSF) supported the development and demonstration of two major computer-assisted instruction (CAI) systems: Programmed Logic for Automatic Teaching Operations (PLATO) (Murphy and Appel, 1977) and Time-Shared, Interactive, Computer-Controlled Information Television (TICCIT) (Alderman, 1978). NSF also supported a large-scale evaluation of these systems, carried out by Educational Testing Service (ETS). This is the largest evaluation of CAI that has been attempted, so it has become a major piece of literature in this area.

Conceptualization of the two computer-based learning systems was quite different. PLATO is centralized; until recently it was operated totally from the University of Illinois. TICCIT is decentralized, depending only on the local computer. PLATO is designed to be an adjunct to classroom instruction; its exercises, drills, and games are not intended to be a full course of instruction. TICCIT is designed to provide all of the instruction that would otherwise be given through classroom lectures. However, both systems do seek to individualize instruction by providing a variety of materials to match the needs of the student, and by offering immediate, nonjudgmental feedback on performance.

Since the early days of computer-based training (CBT) the accepted method of implementation has been that of presenting the courseware in a large learning center. This may have been more for the benefit of the instructors than some deficiency in the CBT programs. In any event, this presentation strategy has become the norm for most CBT programs. Multiple student stations, frequently tied together over a local area network (LAN), using a large file server for courseware storage, and often under the real-time control of an instructor using a dedicated console has become the accepted standard.

There are both positive and negative attributes to centralized CBT training, and there are be strong advocates in both camps. In support of the centralized learning center concept is the immediate availability of subject matter experts (SMEs) and adjunct resources to resolve unanticipated student difficulties as they arise. In essentially real-time, students having difficulties in a training program can be given one-on-one remedial instruction, extra assignments outside the curriculum, or personalized hands-on exercises. In the majority of cases, this attention is sufficient to eliminate the noted learning difficulty.

On the other hand, maintaining a centralized training facility for a widely disbursed workforce is expensive and, in many cases, not very effective. Initial training is adequately satisfied at the training command. However, the continuing need for refresher training or upgrade training on an evolving weapon system requires the technicians to return to the centralized training facility. This is expensive in terms of both expended resources and reduced operational readiness.

TRANSPORTABLE COMPUTER-BASED TRAINING (TCBT)

The implementation of transportable CBT easily supports initial training, refresher training, upgrade training, proficiency maintenance, and tactics; all on a personal computer without the

need for the allocation of additional training resources. This approach equally supports operator, maintenance, and team training. (See Figure 1)

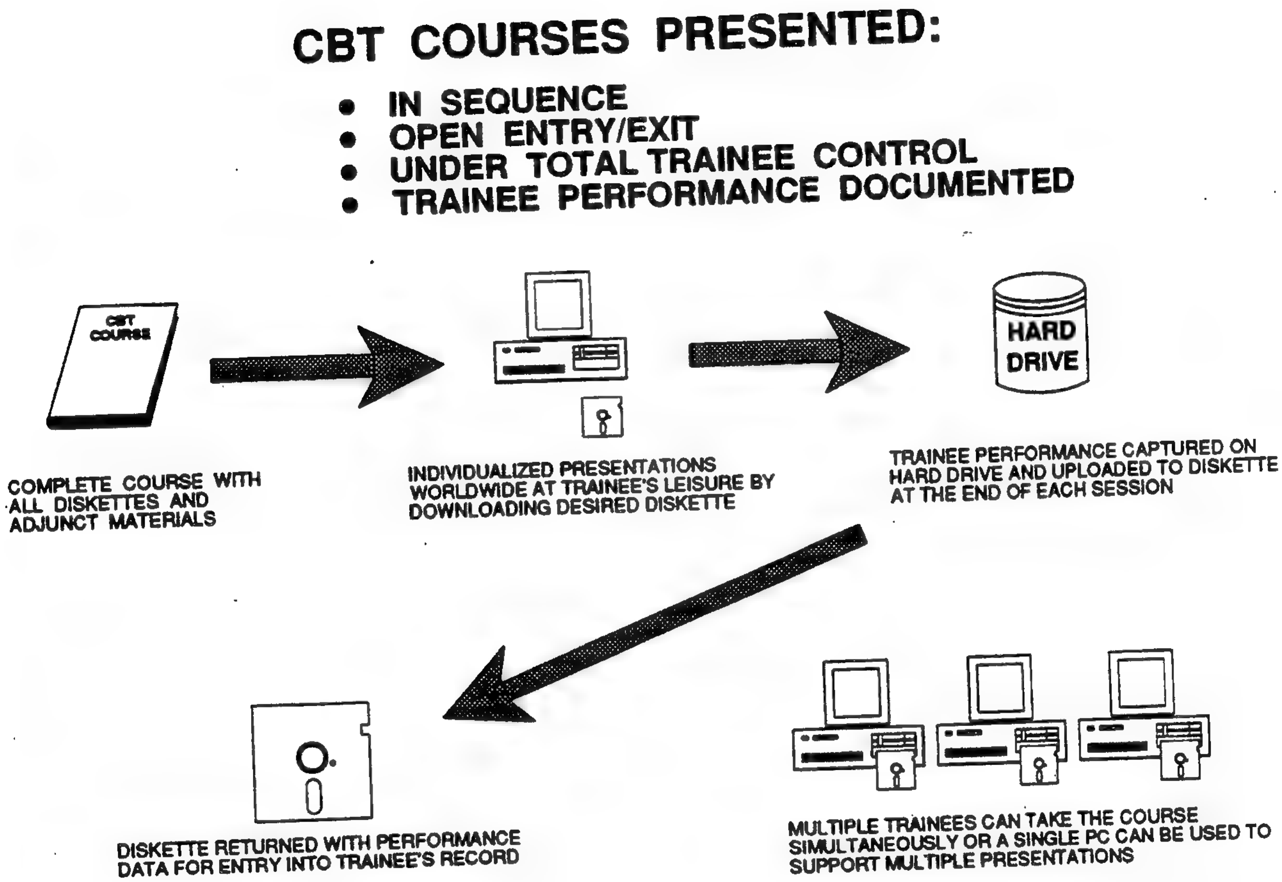

Figure 1. Transportable Computer-Based Training (TCBT)

The trainees use a self-paced workbook and computer-assisted lessons and exercises to acquire or maintain technical proficiency across a large spectrum of technical disciplines. Controlled simulation scenarios allow hands-on practice to gain confidence and mastery. When the modular workbook and computer-assisted exercises are combined they provide a complete self-paced training program that satisfies initial, refresher, and upgrade training requirements. Separated, these components stand alone as modules for review, testing, or job aids long after the initial training is completed.

Initiating Training

It is anticipated that training might be initiated in one of two different ways: the technicians could request a specific training program through the local educational officer or the weapon system provider could include the training program as an integral part of the installation or up-grade of the weapon system. In addition, accuracy could be maintained between the required operator/maintainer procedures and any installed operational system through the distribution of concurrent upgraded training programs.

Training packages would be either formal or informal. Formal training includes those programs that are required for advancement, increased levels of responsibility, and new job assignments. In other words, successfully completed training programs would be documented in the trainee's permanent record. Informal training, on the other hand, is that training which supports the existing job assignment by maintaining or increasing the individual's proficiency level. Examples include the practice of a skill that must be performed within a set of strict critera, the performance of an infrequent but critical skill, or reactions to emergency situations that are too dangerous to train on operational equipment.

Presentation of Courseware

Transportable CBT programs are given to the trainees as complete training packages that consist of all presentation software, courseware, and adjunct materials. Trainees simply insert the training diskettes into a PC during inactive periods and progress through the course. Immediate transition from the training presentation back to the operational environment is accomplished by inserting a "bookmark" and exiting the program. Thus, when the operator returns to the training program it is possible to continue from the previous point in the training process. Some major benefits of this approach are: training can be presented in small increments (i.e., 1 hour or less a day as the operational environment permits) without job interruption; travel to a centralized training facility is reduced; and the subject matter may be reviewed time and again as dictated by the operational requirements.

Performance Data Collection

Throughout the presentation of the training courseware, and completely transparent to the trainee, performance data is captured. Collected data may include course information (course number, title, version, release date), trainee information (name, SSN, duty station, work assignment, supervisor, etc), course access (who is enrolled, start and stop dates, how often they access the course, etc), time (in the course and each module, lesson, test), trainee performance (score by course, module, lesson, correct and incorrect responses for each test question, number of remediations, etc), and statistical information for the educational officer, courseware developers, and higher levels of command. When the training package is returned to the originator, this performance data is easily accessed to update records or to generate hardcopy reports.

THE FUTURE OF TCBT

The future applications for this approach are unlimited. The expansion of initial, refresher, and upgrade training applications are certainly viable options, but what about sensor operators receiving updated profiency training prior to deployment (or enroute) that represent specific target characteristics or tactics? Why can't this same approach also be used to pass technical updates in hardware, software, and operating procedures to the fleet either as supplementary materials or to replace hardcopy manuals and printouts?

An additional application might be termed the "what if" scenarios. These would be fictitious, but realistic, scenarios that an operator might face in the operational environment. It could include a saturated air picture, complex fleet activity, tactics simulations, or some similar event that would require precision responses on the part of an individual operator or team. Maintenance personnel could also use this approach on PCs to conduct comprehensive fault isolation, simulating repair and replace procedures, and work-around solutions. The application is limited only by the imagination of the courseware developers and the ultimate users.

Ease of Update

One of the most positive attributes of the TCBT program is its ease of update and distribution. Courseware is always developed as stand alone modules, and where possible, as generic modules (for example, basic electronics is basic electronics regardless of the ultimate application). Instructional designers can then mix and match existing modules with new modules to form new programs or simply add the upgrade changes to reflect the update.

Distribution is easily accomplished by sending a new diskette to each addressee. A software routine will remove and replace the identified module or lesson with the new version. Hard copy updates are accomplished in the same manner using the appropriate word processing system.

Just-in-Time Training

Just-in-time training refers to the courseware that is resident in the operational system. This serves as a readily available performance job aid when needed by the operator or maintenance technician. This has been implemented very effectively in the area of Automated Test Equipment (ATE).

A pull-down menu can be accessed from the operational screen in which specific procedures are made available. This may include a selection of schematics in which the technician can progressively zoom and pan until the area of interest is centrally located on the screen. The technician may then move about the drawing and make notes as desired. Also available is the ability to call a variety of digital files displaying video sequences showing the operator how to perform detailed procedural tasks, for example, how to adjust one of many potentiometers until the waveform shown in the video clip frame is obtained.

Another example might require the operator to PROBE R1, PIN 1 on a circuit board. The board might be shown as a video file with the specific area circled and the probe location indicated on an enlarged video clip. Without this approach, the operator would have to locate a drawing in a Technical Order, then find the part among hundreds of callouts on the page.

CONCLUSIONS

CBT training on PCs avoid having to provide instructors, as well as reducing the cost and eliminating the inconvenience of scheduling operators and technicians to take conventional classroom

instruction during their off-time. The achievement of training goals and the coordination of training resources and personnel to be trained in an active operational environment is a very difficult task. TCBT provides a viable alternative.

Another desirable feature of TCBT is its automatic documentation of trainee progress. The CBT program tracks lesson completions by date, records student scores, and provides other much needed data as defined by the users. Courseware can even be developed to freeze the presentation after a specified number of errors and force the trainee to seek the help of his supervisor before continuing.

And finally, trainees, for the most part, need help managing their learning. TCBT maximizes the use of active student participation, feedback, and an enriched learning environment. As an added benefit, trainees learn on the actual hardware of their operational position for which they will ultimately be held accountable. This provides a level of confidence that could never be achieved in a centralized learning center.

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Lange/1301
6 December 1991

Total Quality Leadership Awareness Training

by: Wally Lange
Naval Ocean Systems Center
Associate for TQL

There is a new leadership concept being advocated at the Naval Ocean Systems Center known as Total Quality Leadership or TQL for short. TQL is both a philosophy and a set of guiding principles that represent the foundation of a CONTINUOUSLY IMPROVING organization. TQL is the application of quantitative methods and human resources to improve the material and services supplied to an organization, all the PROCESSES with the organization, and the degree to which the NEEDS OF THE CUSTOMER are met, now and in the future. TQL integrates fundamental management techniques, existing improvement efforts, and technical tools under a disciplined approach focused on CONTINUOUS IMPROVEMENT.

The above is the Department of Defense's definition of TQL and is the starting point for all DoD activities as they move toward implementing TQL within their respective commands. At the base of the structure for implementing TQL at any command is the critical need to have all individuals have an understanding and working knowledge of the intent, direction, scope and planned results of the TQL effort. At the Naval Ocean Systems Center, Wally Lange, the Center's Associate for TQL, has developed and conducted TQL Awareness classes for the past year and a half. Over 650 Center employees have attended classes to date. The reason the Naval Ocean Systems Center has taken such an aggressive effort to implement TQL can be clearly seen for the the following reasons. First, TQL has the highest level of support from the Secretary of the Navy, the Chief of Naval Operations, and the Commander, Space and Naval Warfare Systems Command. Secondly, the implementation of TQL requires that all Center employees become aware of its principles, goals, and the methods by which the Center plans on implementing TQL.

Questions that this paper will address are how can an organization conduct effective TQL Awareness Training, obtain the latest thinking on the subject material, and make the training relevant to the individuals being exposed to the TQL philosophy.

To begin with, the single most critical element of the training effort is to have the full support and enthusiastic backing of the activity Commander or Commanding Officer as well as the top management personnel within the organization. When the Chief of Naval Operations says to audiences that, "He is still learning about TQL" it is fairly safe to say that all others within the Navy, military and civilian alike, should have the same viewpoint of their own education in the matter. The Navy is quickly developing standardized and appropriate level training courses that will soon be available to all Navy Commands. Training courses are also available now from the Federal Quality Institute, that is part of the Office of Personnel Management. However, the problem two years ago was that these above mentioned training resources were not available to Department of Defense activities.

The Naval Ocean Systems Center and its sister Research, Development, Test and Evaluation laboratories needed to institute training then and there during the 1989-1990 period. The route taken, and one that proved for the Naval Ocean Systems Center to be highly effective, was that a self-developed command Total Quality Awareness Training Course was produced. It was produced by having a few individuals, research the available written material, share ideas among a team of "TQL Coordinators" from the various laboratories, and then develop appropriate outlines and viewgraphs to support the training points.

Two major documents that supported the TQL doctrine were the Total Quality Management Guide - Volume I (Key Features of the DoD Implementation) and Volume II - (A Guide to Implementation), Published by the Deputy Assistant of Defense for Total Quality Management, these documents provided the best "current thinking" on the subject upon which to add additional relevant information. The most significant additional information was from the writings, books and articles by the master of quality in the United States, Dr. W. Edwards Deming.

The next step was the need to identify and appoint a few dedicated, knowledgeable, motivated, and convincing individuals to research the available material, distill the key pearls from it, and develop and present the material in an interesting and enthusiastic way to the individuals initially interested in learning more about TQL.

At the Naval Ocean Systems Center, it was top management's desire to have every employee hear the TQL Awareness training message, but it did not want to mandate that individuals attend. Better, was to have the initial recipients hear the message and then by word of mouth and verbal praise of the course, convince and/or influence others to attend. Thus the "pebble in the smooth pond" theory with its ever spreading areas of influence has been the experience at the Center. To date over 650 individuals have participated in the TQL Awareness training, about 20% of the entire Center population. Also significant is that approxiamtely 225 of these individuals are working as members of the Center's Executive Steering Group, six functional areas Quality Management Boards and/or 20 Process Action Teams and are actually using the principles of TQL to make actual changes in the way we do business. This then also becomes a "pebble in the smooth pond" approach to having more and more individuals actually involved with and experienced in the process of continuously improving everything we do.

The TQL Awareness training should be of an overview nature and not so specific as to bog down in minor details. In summary the two sessions of three hours each are taught on separate days, usually in the morning and address the following subjects:

- Why TQL is needed.
- 15-minute video by the CNO on why it is important to him.
- TQL Doctrine - (Short overview of 45 minutes)
- Discovering the Future: The Business of Paradigms. Video by Joel Barker
- Overview of Dr. Deming's 14 Management Principles
- Tools and Techniques used to collect and display process data.
- How the TQL Infrastructure (Executive Steering Group, Quality Management Boards, and Process Action Teams) operates with each other in relation to the existing and traditional line management organizations).
- Concludes with an inspiring and informative Video by Tom Peters - "A Passion for Excellence"

What is vital in our opinion, is that the training must be conducted in relative small classes of from 20-40 individuals in a setting that allows for an open exchange and discussion of the points made by the instructor. In the 35 or more classes conducted, no two are the same because of the class participation. What we are trying to do is not so much to teach them something, but to get them to think that something is fundamentally different about how we are going to do our business in the future. The major difference is that we will have top to bottom participation, and an atmosphere of more and clearer communications between all levels and Center organizations, both vertically and horizontally. Thus the classes are likewise a mixture from all levels and departments to show how powerful the dialogue aspects of the TQL effort can be.

Finally, we strive to show the participants that this "continuous journey toward improving quality" can and will be very enjoyable. Feedback from our initial teams is that they thoroughly enjoy the working atmosphere when the teams have experienced a growth in group dynamics and a high level of trust among the 6-8 members is evident in their week to week meetings.

Adding to the TQL Awareness training are periodic visits to the Center by corporate leaders at the Vice President and General Manager level who present eye-opening stories of how they have had dramatic turnarounds and outstanding results when the principles of TQL are applied.

It all begins with the first step of employee TQL awareness training and what follows will be amazing.

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About the Author: Wally Lange is a management analyst at Naval Ocean Systems Center and is the Associate for TQL, Code 1301. His 20 year management analyst/Naval Reserve officer career has included management reviews, manpower determination studies, and the development of staffing standards. He received his BA degree in business administration from Duke University. For further information, please call Mr. Lange at (619) 553-4730 or AUTOVON 553-4730.

WEAPONS TRAINING TEAM BI-ANNUAL PMA205 WEAPONS TRAINING 2000 MEETING LIST OF ATTENDEES

Mr. William Adams	Hughes Training, Inc.	1200 E. San Bernardo Rd.	West Covina, CA	91791
Mr. Charles Agel	Star Mountain, Inc.	113 Clermont Ave.	Alexandria, VA	22304
Mr. Matthew Anderson	NAWC, Code 36		China Lake, CA	93555
Mr. Mike Anderson	VP-31 ISD		NAS Moffett Field, CA	94035
Mr. Dennis Askvig	JMK, Inc.	2626 Valley Lake	El Cajon, CA	92020
Mr. Gary Barnes	NSWC I.H. Div, Code 3930J		Indian Head, MD	20640
Mr. George Barrett	NAWC, Code 2033		China Lake, CA	93555
Mr. Stephen Barthel	NUSC, Code 8313		Newport, RI	02841
Mr. Alfred Bartkoski	Ketron	1725 Jefferson Davis Hwy, Ste 602	Arlington, VA	22202
Mr. Toni Bell	NWC		China Lake, CA	93555
Mr. Thomas Benedik	NSWC I.H. Div, Code 650Z		Indian Head, MD	20640
Mr. Thomas Bennison	Loral	1127 W. Reeves	Ridgecrest, CA	93555
Mr. Carl Bergsneider	Loral	1210 Massillon Rd.	Akron, OH	44315
Mr. Bruce Betschois	NTSC		Camp Pendleton, CA	92055
Mr. Arlie Blackshear	NTSC, Bldg 2394		Camp Pendleton, CA	92055
Mr. Robert Blair	Grumman	Sunrise Hwy Mailstop B28043	Great River, NY	11739
Mr. Gerald Borrello	Raytheon	1847 W. Main Rd.	Portsmouth, RI	02871
Mr. Chris Boschen	Cubic	9333 Balboa Ave., Ms 2-3	San Diego, CA	92123
Mr. John Bowles	NSWC I.H. Div		Indian Head, MD	20640
Mr. Brian Boyle	Technology Appl	200 Professional Drive	Gaithersburg, MD	20879
Mr. Robert Bragunier	NSWC I.H. Div.		Indian Head, MD	20640
Mr. Richard Brogan	Intel Corp.	5000 W. Chandler Blvd.	Chandler, AZ	85226
Mr. Raymond Brown	McDonnel Douglas MC 288 2040	12301 Mo. Bottom Rd.	Hazelwood, MO	63042
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Mr. Kel Collins	NAVAIRSYSCOM PMA 205 1H11T		Washington, DC	20361
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Mr. John Crawford	NUWES, Code 60J		Keyport, WA	98345
Mr. Patrick Dailey	Star Mountain, Inc.	720 N. Norma St., Ste. B	Ridgecrest, CA	93555
Mr. Sidney David	Grumman	Sunrise Hwy, M/S B23-043	Great River, NY	11739
Mr. Richard Davis	Regency Sys, Inc.	3200 Farber Drive	Champaign, IL	61821
Mr. Donald Decker	NavAvionics Center		Indianapolis, IN	46219
Mr. Kenneth Doris	Grumman	Sunrise Hwy	Great River, NY	11739
Mr. John Dressel	Quintron Corp.	3901-L Centerview Dr.	Chantilly, VA	22021
Mr. Barry Dunn	EER System	50 Enterprise Ctr.	Middletown, RI	02840
Mr. Orlando Duran	NCCOSC RDT&E Div., Code 922		San Diego, CA	92152
Mr. Nick Edgington	Foster Miller, Inc.	195 Bear Hill Rd.	Waltham, MA	02254
Mr. Robert Elliott	PMTC		Point Mugu, CA	93042
Mr. Bruce Epperly	Lockheed Aeronautical System		Marietta, GA	30063
Mr. Dan Evans	Litton Guidance	5500 Canoga Ave., MS-27	Woodland Mills, CA	91367
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Mr. Mark Fowler	Schools Company Co.	HQBN MCLB	Albany, GA	31705
CDR Donald Fox	NAVAIRSYSCOM PMA 2051H1		Washington, DC	20361
Mr. Sheldon Fox	Harris Corp.	P.O. Box 94000	Melbourne, FL	32902
Mr. Marion Freeman			NAS Patuxent River, MD	20670
Mr. Kenneth Frieder	Bionetics Corp.	600 Louis Drive, Ste 203	Warminster, PA	18974
Mr. Charles Garverick	Richards Carson & Associates	999 Strauss Ave.	Indian Head, MD	20640
Mr. Thomas Gehl	IBM	9500 Godwin Drive	Manassas, VA	22110
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Mr. Mort Goldman	Virto Corp.	14000 Georgia Avenue	Silver Spring, MD	20906
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Mr. Jim Johnson	Grumman Space & Elect. Div.	Sunrise Hwy	Great River, NY	11730
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Mr. William Jones	NAMO 442		NAS Patuxent River, MD	20670
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Mr. Bob Kane	Cubic			
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Mr.	William Miller	Norden Systems	75 Maxess Rd.	Melville, NY	11747
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Mr.	William Muhlhausen	NWC, Code 3661		China Lake, CA	93555
Mr.	Kenneth Murakami	NUWES, Code 9034		Lualualei, HI	96792
Mr.	Lee Myrben	Eldyne, Inc.	9775 Clairemont Mesa Blvd.	San Diego, CA	92124
Mr.	Peter Nann	Aquidneck Data Corp.	170 Enterprise Center	Middleton, RI	02840
Mr.	Bruce Napp				
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Mr.	George Saunders	NTSC		Camp Pendleton, CA	92055
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